The

ENGINEERS' DIGEST

REVIEW OF ENGINEERING PROGRESS ABROAD

VOL. III. No. 10 OCTOBER, 1942

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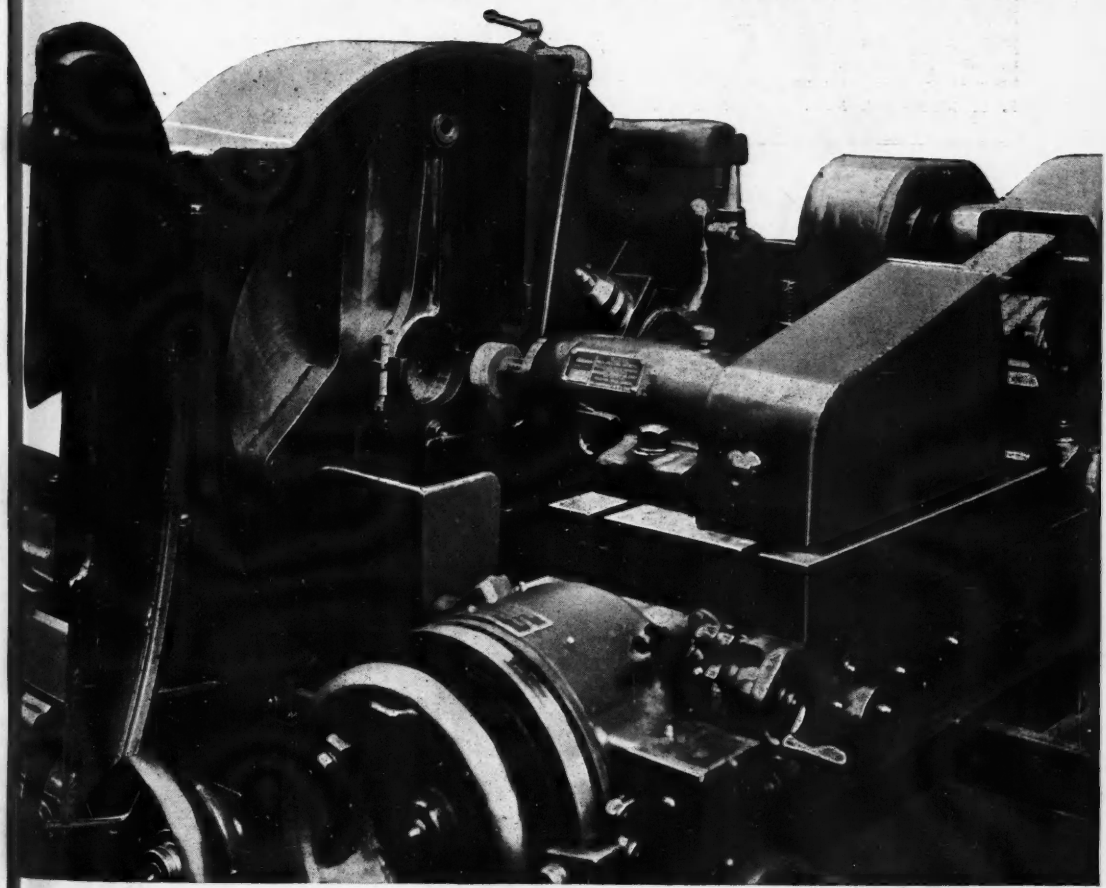

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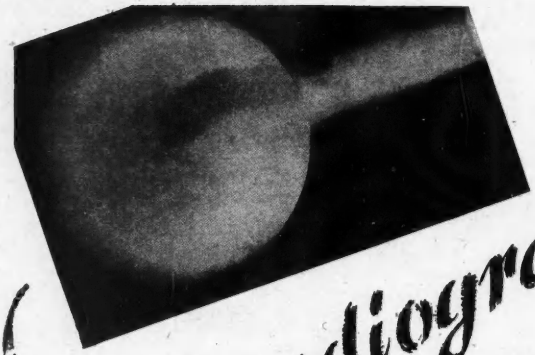

The radiograph reveals

what destructive examination confirms

This is an instance of the value of radiographic examination. The blow-hole in the aluminium casting is revealed in the radiograph, yet the casting remains undamaged and fit for use if the flaw is judged not to be serious. In this case, however, the evidence of the radiograph has been confirmed by sectioning the casting to expose the flaw—which is clearly seen in the photograph of the sectioned casting. Thus in the routine testing of castings radiography ensures flaw detection, but leaves the casting intact. 'IndustreX' D, 'IndustreX' S and 'CrystalleX' are X-ray films specially produced for such industrial radiographic purposes as the examination of castings, welds, and other engineering produce.

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AGRICULTURAL TRACTORS USING PRODUCER GAS

By DR.-ING. H. LUTZ, Berlin. (From *Zeitschrift des VDI*, Vol. 86, No. 23/24, June, 1942, pp. 359-366).

IN the intensification of agricultural production not only in Germany, but also over the whole of Europe, the rubber-tyred agricultural tractors play an important role. As conversion from liquid fuel to producer gas is unsatisfactory at its best, research was carried out to find the best gas producers and producer gas engines. The following essay shows the work done to obtain standard equipment and further deals with new engines, gears shorter than previously used, and general assembly of the producer gas tractor.

Development of Vehicles and Engines.

The rubber-tyred tractors are most vital to the saving of labour and the increase of production in agriculture. Though the number of tractors in the Reich has been nearly trebled since 1938, only one-tenth of the total number planned are as yet available and there is, therefore, considerable room for mechanisation. To that must be added the increase due to the occupation of vast territories in the east, with their rich farm lands and the necessity of the other European countries to intensify their agricultural production; the number of tractors required will thus run into millions.

Possibilities of Future Fuels for Tractors.

As rubber-tyred tractors are not only used for sowing and harvesting, but also for other farm work, including that of stationary engines, a working period of 1,500 hours per annum is assumed for each tractor. A medium sized machine would require approximately 5 tons of diesel oil for this period, and thus the total requirement of all agricultural tractors used in Europe can be estimated. In the future, however, a corresponding increase of mechanisation in industry will make increasingly greater demand on liquid fuel, which will become scarce, and necessitate big savings. It must be also remembered that aero engines, for instance, are precluded from using other fuels.

Choice of Fuel.

Solid fuel would seem the only substitute for the liquid fuels used in agricultural tractors. Gaseous fuels such as butane and propane are eliminated owing to their excessive cost and the difficulty of transporting the bottles in which they are supplied. Gases of medium calorific value, such as hydrogen and coal gas, are impracticable because the quantity of heat that is possible to store in one cylinder, would be insufficient and necessitate frequent change of cylinders even when the gas is highly compressed.

An equally important factor in favour of solid fuels is their cheapness which counts all the more because of the small margin of profit in agriculture. The solid fuel, be it scrap wood or coal (anthracite, brown coal or coke), promises to remain a cheap fuel for a considerable period; an increase in the price of these fuels is not to be expected. Wood or coal are also more easily stored and transported than liquid fuels, which require regulation storage plants.

Producer-gas tractors will always be useful where the price of transport makes up a considerable part of the price of the fuel; e.g., in the Colonies.

Producer-Gas Tractor Development.

The four-year plan had realised the necessity or agricultural tractors run on producer gas as early as 1937, but to speed up research the " Forschungstelle Gasschlepper Entwicklung " (Research Institute for the Development of Producer-Gas Tractors) was given the problem of co-ordinating the tractor engines, gas producers, and gear designs. The research aimed at producing an efficient producer-gas tractor using new materials and completely new designs if necessary. The war has not much altered the position, except that now the available tractors are taken as a basis for work, and that a much closer time limit has been set to the institute to complete its task.

Adaption to Agricultural Conditions.

The condition of trouble-free running of producer-gas tractors cannot be compared to those of lorries: whereas the driver of the latter is always a skilled man, the former is driven by a man (or even a woman) who must be able to do a thousand and one other jobs on the farm, apart from driving. Only rarely will such driver have the mechanical knowledge that would be desirable. Furthermore, workshops and garages are not as easily accessible to tractors as to lorries. Repair and maintenance, therefore, becomes much more cumbersome.

The greatest difficulty encountered when a change-over was attempted, was the fact that one could not convert tractor engines to producer-gas engines. The since perfected semi-Diesel engines using the two-fuel system were still in their experimental stages, and due to the loss in power, Diesel engines could not be converted to the Otto cycle. A 22 H.P. Diesel engine, for example, was reduced to 16 or 17 H.P. on conversion to producer gas, and thus too weak for the work for which it was originally designed. A large percentage of German tractors are semi-Diesels, which cannot be easily converted to producer-gas engines. Only after Messrs. Lanz had completed exhaustive research, could a two-stroke semi-Diesel engine be converted to a producer-gas engine.

The Constructional Development of the Producer-Gas Tractor.

The first difficulty is the location of the gas producer plant. Whereas in a lorry there is a platform where the gas-producer can be fitted, the tractor consists essentially of nothing but a frame supporting the engines and there is no room for the gas-producer.

It is impossible to fit the plant behind the driver's seat as such a position would interfere with the appliances towed, and would be uncomfortably hot for the driver. Furthermore, the front axle would, on some engine types, carry an insufficient load. The gas-producer in front of the radiator would cause excessive loading on the front axle. Thus, only the side remains, and Fig. 1 shows an example of this type.

This tractor is unsymmetrical and gives the impression of being incomplete. The distribution of weight on the two axles, which plays a considerable part in agricultural tractors, worsened, because at least half of the weight of the gas-producer is added to the load on the front axle. The visibility of the driver is reduced, and the accessibility of engine parts becomes so bad, that when repairs have to be carried out, some parts of the gas-producer must be dismantled.

To remove some of the above mentioned disadvantages, the gas-producer may be fitted over the tractor engine. If the engine is built well up in front, or fitted with specially long gears, the gas-producer and its filters may thus be inserted. The first advantage of this arrangement is the ease with which the gas-producer, which is fixed only with a few bolts and nuts, may be dismantled. Furthermore with the usual distance

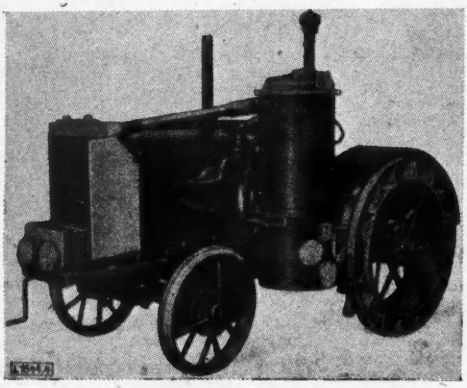


Fig. 1. Agricultural tractor fitted with Imbert gas-producer.

between the axles, it is comparatively simple to build a producer-gas tractor (using available parts) which has a symmetrical appearance. The first design by the "Reichsamt fuer Wirtschaftsbau" in 1937 was, therefore, along these lines. The disadvantages of this system are: poor visibility for the driver, excessive load on the front axle and the impossibility of fitting a grass-mowing attachment of usual design.

After considerable research had been done in this field, the following arrangement for a producer-gas tractor was recommended by the "Forschungstelle": Tractors using liquid fuel require certain overall dimensions to obtain a suitable distance between the axles and distribution of load, both of which are essential for road-staying power and ease of steering. Most of the gearing is therefore longer than is necessary for the clutch mechanism and transmission. The gear box of the tractor is therefore shortened in such manner as to make room for the gas-producer including filters and gas-cooler to be fitted between the engines and the front axle. Even if it is impossible to install the complete gas-producer, at least a substantial part may be put there.

If in addition as short an engine as possible is used (e.g., a two-cylinder engine), sufficient space is provided with the usual distance between the axles to enable the complete gas-producer to be fitted between engine and front axle. A similar shortening of the engine and gears is also obtained if the engine is mounted crossways or by using a V engine.

Fig. 2 shows the design of a producer-gas tractor along the above mentioned lines. The gas-producer is developed as a single unit, fitted between engine and front axle, while the filters are partly before the front axle. The lower part of the gas-producer serves as carrier to the axle. The gas-producer thus becomes an integral part of the tractor.

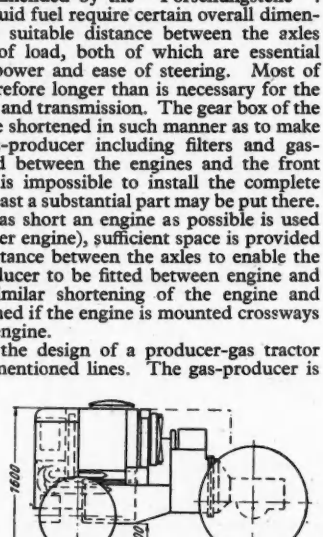


Fig. 2
General Assembly and overall dimensions of a producer-gas agricultural tractor with shortened gears, and a gas-producer carried on the front axle. (Design).

The shortening of the engine and gears leads to a considerable reduction in weight, particularly as the heavy gear casing has also been reduced. What is especially important, however, is that the centre of gravity of these parts, has been shifted towards the back axle. This means that the additional weight of the gas-producer does not lead to any considerable increase of the load on the front axle. Thus with suitable construction it will be possible to build producer-gas tractors whose overall dimensions are the same, which are not heavier than the equivalent liquid fuel tractors, and in which the distribution of load on front and rear axles is the same.

A tractor towing agricultural appliances must have a minimum dead weight to ensure adhesion of the wheels. It was, therefore, necessary either to fit weights to it or else make some parts, such as wheels, castings, etc., heavier than would have been necessary from purely mechanical considerations. For new designs the extra weight would be supplied by the gas-producer and the shortening of gears helps to balance the weights. It will then not be necessary to choose a particularly light gas-producer, and the parts exposed to corrosion and to wear by continuous heat may be constructed of such thickness as to give them a working life equal to that of the tractor itself.

The "Forschungstelle" apart from theoretical records, has carried out practical tests with its own tractors.* These have run a total of over 12,000 hours; all faults and conditions of running were carefully observed and valuable information was gained.

The first problem that had to be solved was whether soft and pine wood alone, i.e., without addition of hard wood, could be burnt for longer periods in the producer. Other laboratories had proved the theoretical possibility, but there was no record of a continuous trial. It was found that by suitably constructing the gas-producer and the use of a filter plant designed for greater amount of dust, continuous working was assured using soft wood, or even wood of poorer qualities. The details of construction were noted and in the meantime pinewood was used during 90% of the working hours.

On field tests it soon became obvious that the behaviour of the gas-producer with an amount of the moisture from the wood had a marked influence on the power output of the tractor engine. Whilst some gas-producers could give satisfactory output using wood of 25% moisture content, others were unable to supply sufficient power to move the tractor along. After storage for a year, green wood still contains 15% of moisture and great stress was therefore laid on constructing a gas-producer less sensitive to moisture, particularly as with the increase of gas-producers using wood, it would be impossible to dry the wood even to such extent. As a result of extensive research only thermodynamic measures were taken to reduce heat losses during the process of combustion.

Gas-producers using the Imbert process were found to require excessive amounts of charcoal in the outer combustion chamber. A 25 H.P. tractor, for instance, used 0.3 kg. per working hour when tested. For large numbers of producer-gas tractors this would lead to impossibly large quantities of charcoal (30,000 tractors would require approximately 1,000 tons of charcoal per annum). Ways avoiding this waste therefore had to be found.

*Two of these are running on bituminous fuels.

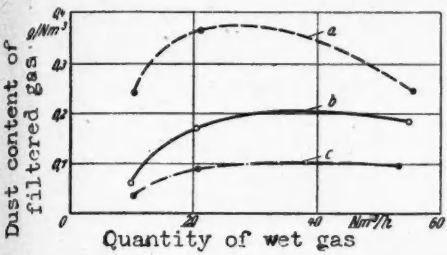


Fig. 3. Cleaning efficiency of the most important filters (cleaning gas-produced from pine wood) : (a) filtration by cooling ; (b) filtration using oil ; (c) glass-wool filter.

A further problem was the period the gas-producer could be used without cleaning the combustion chamber. By allowing ample space for the combustion chamber and adopting a suitable construction of the grate, the working period was brought up to 1,000 hours. The work of cleaning thus becomes negligible.

Amongst the most important parts of the gas-producer is the filter plant. This must be small, give good service during all seasons, require little attention, and can be capable of filtering the dust satisfactorily. Particularly important is the servicing. For an agricultural machine this must be as low as possible, owing to the acute shortage of labour. Should it be excessively high, the farmer will shorten it himself by omitting certain tasks of maintenance altogether, particularly in times of sowing and harvesting. The result would be that the filters would clog up and become ineffective, leading in turn to a breakdown of the tractor either due to excessive wear of the engine, or clogged gas pipes. The need for a filter plant requiring little or no maintenance cannot be too strongly emphasised. On experimenting with various types of filters it was found, that some having three times the efficiency required only one-third the maintenance.

The way the maintenance is carried out is also very important : although filters requiring washing with water under a pressure would seem suitable, on reflection it becomes obvious that they would not serve well in practice. There may be a tap in every farm yard, but there is not always a hose ; the tap might freeze in winter and in any case the tractors remain in the fields where they had been working very often, or at best are put into a barn or shed where water would not be readily available.

By testing some well-known filters, taking the dust content of the filtered gas as a criterion, the superiority of the glass-wool filter was proved (see Fig. 3).

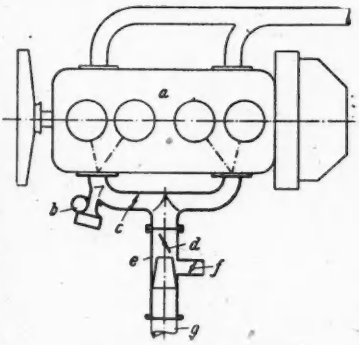


Fig. 4 Hansa starting system. Two cylinders act as gasoline engine, the other two as suction pump ; (a) engine ; (b) carburettor ; (c) exhaust cut-out; (d) mixing valve; (e) mixing chamber ; (f) air vent; (g) gas pipe.

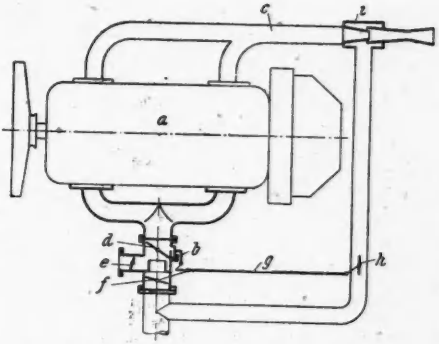


Fig. 5. Solex starting system. The exhaust gases of the petrol driven engine create, by means of an ejector, a suction on the gas-producer : (a) engine ; (b) carburettor ; (c) exhaust ; (d) throttle valve ; (e) air valve ; (f) gas valve ; (g) joint connecting rod ; (h) ejector valve ; (i) ejector.

The substitution of refractory materials for the nickel-chrome steels that had been used for the lining of the firepot, sets another problem. After satisfactory results had been obtained by some gas-producer manufacturers using refractory materials, it was decided to use these in preference to steel which has to be renewed at intervals. With correct construction of the firepot (the variation of temperature must be taken into account) the use of heat-resisting bricks tongued into one another was found suitable as well as quick and cheap to repair. (Process of Hansa Gas Generatoren Ges.) There are further some thermodynamic advantages as compared with steel.

Producer-gas engines are not as easily started as those using liquid fuels ; the time of starting, however, is very important to ensure speedy availability at all times. After careful study of all available means of starting, the use of a small amount of petrol was found necessary to ensure quick starting in winter and to make the driving in and out of closed garages safe for the personnel from the danger of poisoning. Two means of starting were devised (Figs. 4 and 5) which use the petrol engine directly (Fig. 4) or indirectly (Fig. 5), where the exhaust gases create a suction effect. Fig. 6 shows the time of starting which are now satisfactory.

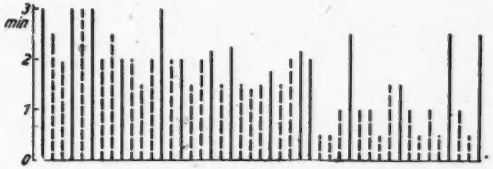
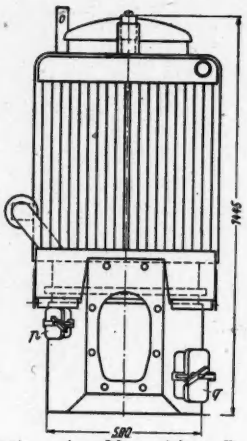


Fig. 6. Total number of times of, and the times required for starting an experimental producer gas tractor fitted with Solex (Fig. 5) during 15 days. Full lines : Starting the cold engine ; Dotted lines : Starting after intervals of work while the combustion zone was still hot.

Standard Gas-Producer for Tractors.

The " Forschungstelle " was given the task of picking out the best parts of all the available types of gas-producers, and co-ordinating them into one whole. Recent thermodynamic improvements were also incorporated. Fig. 7 shows the complete standard gas-



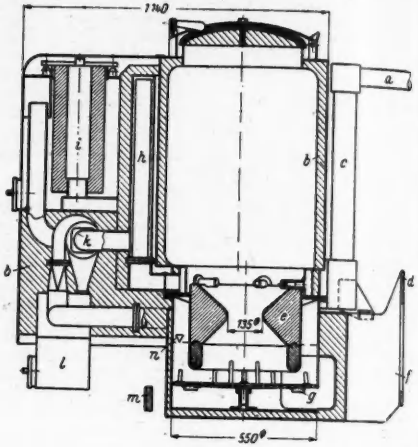


Fig. 7. Standard gas-producer for 60 Nm³/h gas output. Charge: 9 kg charcoal, 50 kg pine wood. (a) gas pipe to the engine; (b) insulation; (c) gas cooler; (d) connecting flange (to motor); (e) refractory furnace; (f) frame; (g) revolving grate; (h) heat exchange; (i) cleaner with glass-wool filter; (k) centrifugal cyclone; (l) dust box of cyclone; (m) front axle of tractor; (n) charcoal level; (o) chimney; (p) charging door for charcoal; (q) ash pit drop door.

producer for an engine with shortened gear box. The lower part of the gas-producer is insulated and inserted into a casing which carries the front axle. The combustion chamber is fitted with double walls to prevent heat losses. The space between walls is filled with insulating material. The firepot is based on the Imbert principle, but lined with refractory. Waste of charcoal has been avoided by good design of the outer and inner combustion zones. The gas is cleaned in a cyclone extractor. In the heater-cooler that follows, 50% of the sensible heat is given to the air entering the gas-producer. The final cleaning is done by two glass-wool filters. Using pinewood, the dust content of the filtered gas is 0.1 g/Nm³. Finally the gas is cooled in a gas-cooler, fitted in front of the radiator. A similar type of gas-producer is constructed for converting liquid fuel tractors to producer-gas (cf. Fig. 1.) Peat can also be used in this gas-producer for continuous working, provided that ash content is less than 2.5%. The gas-producer reacts only very slightly to the moisture content of the wood. Thus the power output of a 50 H.P. experimental tractor dropped to 34 H.P. when the moisture content increased from 15% to 40%.

Development of Gas Engines.

It is obvious that for an efficient producer-gas tractor the engine would have to be designed with a view of using producer-gas only; conversion of existing engines would be unsatisfactory. Klöckner-Humboldt-Deutz in 1939 developed such an engine. It is a two-cylinder gas engine, with 4 *l* capacity and a speed of 1,550 r.p.m. The compression ratio is 8.5 to 1. The engine is very short and thus fulfils its requirements. (Fig. 8.) On official request several firms joined to

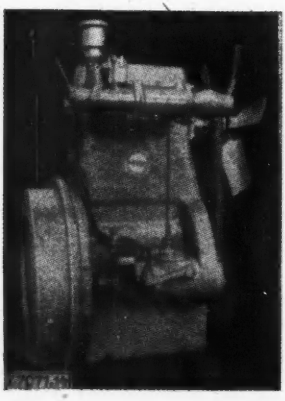
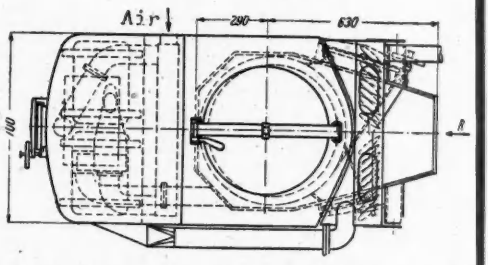


Fig. 8



build 25 H.P. engines with standard connections and flanges based on this design. A future development of this engine consisting of four cylinders is planned with a view to doubling the H.P.

Parallel with this design the two-cylinder 30 H.P. engine is being developed by the "Maschinenbau und Bahnbedarf A.G. Berlin-Babelsberg," see Fig. 9. This shape makes for a further shortening which is advantageous for the final assembly.

Apart from these engines using pure producer-gas, the two fuel-system will be used in future. It is impossible, as was mentioned previously, to convert semi-Diesel engines to use producer-gas efficiently. The

Fig. 9

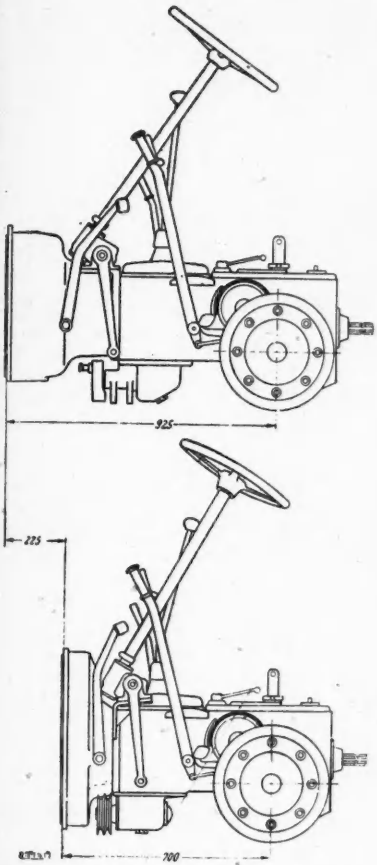


Fig. 10. Shortening of the gears of producer-gas tractors.

two-fuel-system or diesel-gas system, i.e., the conversion of existing diesel engines to producer-gas plus a small amount of oil, will be reserved for the large engines only. Owing to the short time allowed, it has not yet been possible to develop special gas engines for powers ranging from 38 to 60 H.P. This gap can be bridged by the Diesel-Gas system. Using this method, smaller gas-producers can be used, i.e., tractors of 40 to 50 H.P. can be fitted with gas-producers used on producer-gas engines of 25 to 30 H.P.

Development of Short Gears.

The shortening of gears (see Fig. 10) was carried out by shortening the clutch casing without altering the differential to any great extent. The smaller distance between axles may be obtained by further shortening the gears, thus producing types which, while keeping the old speeds, will only be half as long as before.

These producer-gas types are shown in Figs. 11, 12 and 13. After 1st July, 1942, only producer-gas type tractors will be supplied to German agriculture.

Coal as Fuel.

Owing to technical difficulties (e.g., ash and sulphur content of fuel) anthracite and other bituminous fuels have not been used. Research, however, is going on, and it is hoped that this cheap and plentiful fuel may be extensively used in the near future.

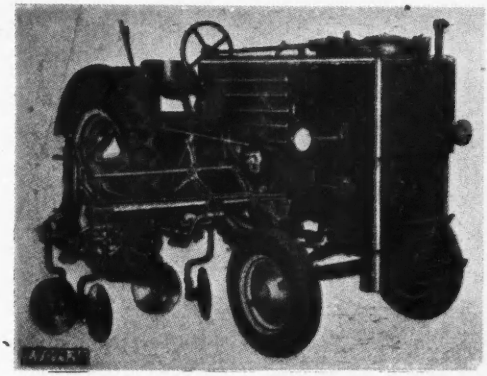


Fig. 11. 15 H.P. producer-gas tractor with standard gas-producer and attachments.

Fig. 12. 25 H.P. Lanz-Buldogg with Imbert gas-producer. The semi-Diesel engine is worked on the two fuel system.

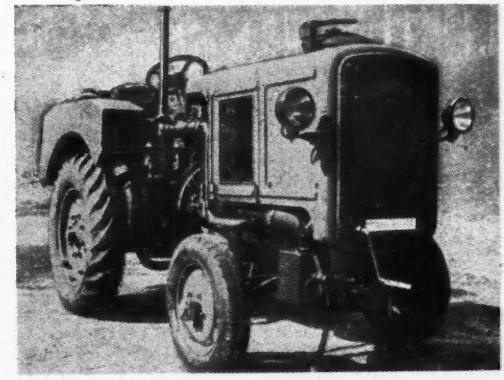


Fig. 13. 25 H.P. producer-gas tractor with Deutz gas-producer and standard engine. The wood is stored above the mudguards, where it is preheated by the exhaust gases.

CONTROL OF HYDRAULIC LEAKAGE.

By CHRISTIAN E. GROSSER. (From *Machine Design*, Vol. 14, No. 8, August, 1942, pp. 70-73).

HIGHEST efficiency of hydraulically operated machines can be attained only by close attention to details that influence leakage. Extended knowledge of the nature of leakage, and improved design resulting therefrom, will make possible increased production and lower costs, and contribute to more widespread commercial adoption of hydraulic machinery. Factors which influence leakage will be discussed in this article from practical and theoretical standpoints, and significant conclusions drawn with respect to their relative importance in leakage control.

The expression $\eta_V = 1 - \frac{Q_L}{N_P D_P S_P}$ .. .. .. (1)

where η_V = the volumetric efficiency of a hydraulic system, Q_L = total volume rate of system leakage flow, N_P = pump speed, D_P = pump displacement per revolution at maximum stroke, and S_P = pump stroke expressed as fraction of maximum stroke, shows conveniently how leakage influences the efficiency of hydraulically operated machines. It applies to all positive displacement systems, and illustrates the important general principles which the designer must recognize in order to minimize the effects of leakage.

The units in which the quantities of Equation 1 are expressed are immaterial as long as the fraction $Q_L/N_P D_P S_P$ reduces to a nondimensional form (pure number). For example, if the total leakage rate of a system be 20 in.^{3} per sec., the pump speed 30 revolutions per sec., the pump diplacement 10 in.^{3} per revolution, and the pump stroke $\frac{1}{2}$-maximum, the volumetric efficiency becomes $\eta_V = 1 - 20$ in.^{3}/sec.$^{-1}$/(30 rev. sec.$^{-1}$ $\times$ 10 in.^{3} rev.$^{-1}$ $\times$ .5 = .867 or 86.7 per cent).

In the first place the quantity Q_L which is a flow rate of the working fluid either as external or internal leakage from the high pressure region to low pressure (usually near atmospheric) is not affected by any operating conditions other than the pressures and temperatures of the liquid.

Pressure theoretically affects the leakage in a linear relationship, i.e., the leakage rate and pressure fall are always proportional for a given leakage path so long as temperature is constant. Actually the leakage increases somewhat more rapidly than the pressure, because pressure increases are generally accompanied by machine part deflections due to the greater forces imposed. These deflections most often open clearances and, therefore, have a secondary effect on the leakage flow.

Operating temperature variations affect the leakage by changing liquid viscosity and also by causing changes in mechanical clearances due to non-uniform temperature distributions through the machine or to unequal expansion coefficients of adjacent parts.

For any given combination of temperature and operating pressures it is possible from examination of Equation 1 to evaluate the effect of the leakage Q_L on the volumetric efficiency under various conditions, and hence on the overall efficiency since the latter may be expressed as the product of three factors:

$$\eta \text{ overall} = \eta_V \times \eta_T \times \eta_e$$

where η_V = volumetric efficiency as before (which measures only the effects of leakage), η_T = torque efficiency (which reflects only the effects of mechanical and fluid friction), and η_e = elastic efficiency (which gives the proportion of recovered stored energy of elasticity, as a portion of hydraulic system descends from high to low pressure).

η_T and η_e are relatively unimportant in almost all current designs of hydraulic transmissions. η_V, however, because of its sensitivity to certain conditions now to be discussed, may become important enough in the whole efficiency picture to be the determining factor in the success of many hydraulic applications.

Referring again to Equation 1 it will be noted the denominator of the term $Q_L/N_P D_P S_P$ simply represents the delivery flow rate of the variable displacement supply pump. (If the pump is of the "constant" type, S_P is 1). Let it be assumed that the leakage rate Q_L is determined at a given temperature and pressure for a complete system such as a transmission. The determination of this total leakage rate may be by direct measurement on an existing machine, or by calculation according to methods to be described later, by which prediction may be made of probable leakage of a proposed design or of a machine on which measurements may not be conveniently taken.

It is plain that the leakage rate Q_L cannot be greater than the delivery of the supply pump, $N_P D_P S_P$, because then η_V would become negative which is impossible, unless another element of the system behaves as an auxiliary supply pump (as, for example, when a fluid motor which has been overcome by its load is being turned backward).

Volumetric efficiency is obviously highest when the ratio of Q_L to $N_P D_P S_P$ is small. The common approach in designing for high volumetric efficiency restricts itself to considerations for reducing Q_L only. While Q_L must certainly be kept to a minimum, this approach alone ignores the possibilities of further helping matters by considering the pump delivery $N_P D_P S_P$ and how it may be made large compared to Q_L.

First of all the speed N_P should be raised to the highest value possible. This is often ignored by de-

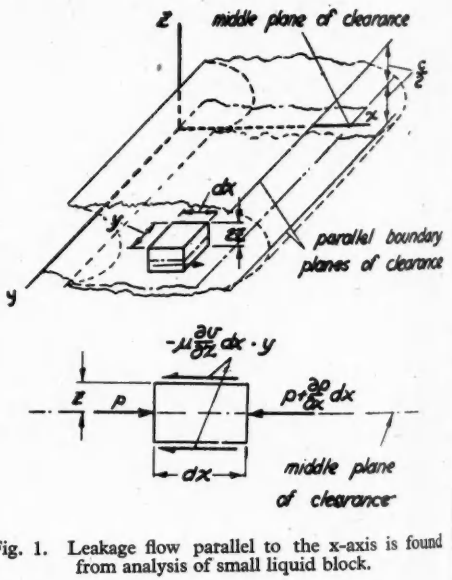


Fig. 1. Leakage flow parallel to the x-axis is found from analysis of small liquid block.

signers and consequently much machinery is seen operating at lower efficiency than that of which it is capable. Increase of operating speed is doubly effective since a higher speed permits transmission of power at lower operating pressures and consequently Q_L is reduced. This further increases the volumetric efficiency since not only is the denominator of $Q_L/N_P D_P S_P$ increased, but the numerator is decreased simultaneously. The same effect may be viewed from the standpoint that a higher speed permits small machinery to carry a given amount of power. Smaller units are inherently less leaky since their clearances are smaller. It is, therefore, axiomatic to operate hydraulic machinery at the highest speeds possible.

Considering Equation 1 further, D_P cannot be increased to improve the volumetric efficiency since a larger displacement unit has an inherently higher leakage rate because of its large clearances (the increase in leakage Q_L is nearly proportional to the increase in displacement per revolution D_P). Furthermore the larger units have a naturally lower operating speed N_P, and, therefore, an increase in unit size should be avoided, and every effort made to operate with the smallest units possible.

The remaining factor S_P, the pump stroke, must be kept large in order to hold up the volumetric efficiency Therefore, a variable displacement pump operating at partial stroke is to be avoided wherever practicable.

Of course, partial stroke pump operation is part of normal hydraulic transmission operation, and while desirably kept to a minimum certain standards of efficiency must often be met with pump operation at partial stroke. The only recourse then to offset the damaging effect of a low stroke S_P is in high speed and low basic leakage rate Q_L.

How serious the matter of volumetric efficiency may become is best illustrated by an example. Suppose a transmission system to have a leakage rate at rated pressure of 10 per cent. of the maximum pump rate. If the pump stroke be reduced to 10 per cent. the transmission efficiency becomes zero. The system is thus useless for power transmission at ratios approaching 10:1 and will be very inefficient at other ratios near 10:1.

Clearances about working parts such as pump and valve pistons and at other sealing surfaces have in many cases been reduced to the order of a few ten-thousandths of an inch by careful finishing and selective assembly. The results have been obtained, naturally, only at great cost, and, in consequence, hydraulic equipment is excessively expensive.

It is interesting and instructive to inquire into the theoretical nature of viscous leakage, as it occurs in positive displacement machinery.

Analysis Evaluates Leakage Factors.

The simplest case of viscous leakage is that of laminar flow between two flat plates of uniform length, with planes oriented parallel to each other as in Fig. 1.

If these plates have a length l in the x-direction of fluid flow, and a difference in pressure Δ_p between the pressures applied to the two ends of the clearance, we may consider what forces act on a portion of the liquid inside the clearance. It will be assumed that the plates have an infinite extent, or width, in the y-direction at right angles to the flow, so that no edge effects need be considered. By symmetry, a liquid particle should be unaffected by its disposition in the y-direction, and we may, therefore, assume that the portion of liquid to be studied is located anywhere along the width of the film.

As will become plain it is more convenient to choose a portion of the liquid located halfway between the boundary plates, and having a thickness 2z where z is the distance measured from the midplane of the clearance.

Now if an arbitrary location be assumed for the liquid in the flow direction it will soon develop that this makes no difference. At all points in the direction of flow the average velocity of an isolated portion of fluid equidistant from the boundary planes will be constant. The liquid portion is, therefore, in equilibrium and the sum of forces acting on it must vanish. Since the forces acting are dependent on the velocity, which does not vary in the direction of flow, the forces must be the same regardless of position in the direction of flow.

Equating to zero the forces acting on a liquid block y 2z dz as in Fig. 1,

$$p2zv-\left(p-\frac{\partial p}{\partial x}\,dx\right)2zv+2\mu\,\frac{\partial v}{\partial z}\,dxv=0 \qquad (2)$$

where μ is the absolute viscosity of the liquid and v the velocity at any level z from the midplane.

Simplifying Equation 2 yields

$$z\,\frac{\partial p}{\partial x}=-\mu\,\frac{\partial v}{\partial x} \quad .. \quad .. \quad .. \qquad (3)$$

Integrating with respect to z (p assumed constant in the direction z),

$$v=-\frac{1}{\mu}\,\frac{z^2}{2}\,\frac{dp}{dx}+C_1 \quad .. \quad .. \quad .. \qquad (4)$$

and from the conditions that the velocity is zero at the boundary plates z and the velocity is unaffected by changes in the x-direction,

$$C_1=\frac{c^2}{8\mu}\,\frac{dp}{dx} \quad .. \quad .. \quad .. \quad .. \qquad (5)$$

$$\text{and } v=-\frac{1}{2\mu}\,\frac{dp}{dx}\left(\frac{c^2}{4}-z^2\right) \quad .. \quad .. \qquad (6)$$

The velocity therefore varies parabolically between the plates and the maximum occurs at the centre, z=0,

$$v_{max.}=-\frac{c^2}{8\mu}\,\frac{dp}{dx} \quad .. \quad .. \quad .. \quad .. \qquad (7)$$

where dp/dx is the pressure gradient in the x-direction, which is constant. In other words the pressure falls from one end of the clearance to the other.

The rate of leakage flow through a width y of clearance will be the average velocity (2/3 of the maximum in a parabolic distribution) taken over the cross section area of the clearance

$$Q=-\frac{2}{3}\,\frac{c^2}{8\mu}\,\frac{dp}{dx}\,c\,y=-\frac{c^3}{12\mu}\,\frac{dp}{dx}\,y \quad .. \quad .. \qquad (8)$$

or in terms of a total pressure drop Δ_p along a clearance length l, having a width w

$$Q=\frac{1}{12}\,\frac{c^3}{\mu}\,\frac{\Delta_p\,w}{l} \quad .. \quad .. \quad .. \quad .. \qquad (9)$$

Fig. 2 shows a concentric piston clearance to which Equation 9 may be directly applied since it is exactly the same as the one-dimensional plate case just derived if the ration of clearance to piston diameter is small.

If the piston is fully eccentric in its cylinder, also shown in Fig. 2, integration will show that Equation 9 may be used, but the leakage will be 2.5 times that for the concentric case.

Examination of Equation 9 shows that the magnitude of the clearance c has a most powerful effect on the leakage, since it appears in the equation to the third power.

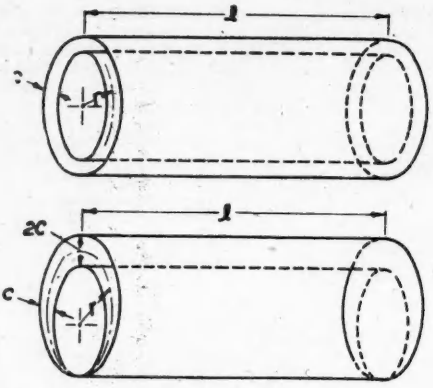


Fig. 2. Upper diagram shows concentric piston clearance, lower shows fully eccentric piston clearance.

As illustration of its effect we may, by halving the clearance, reduce the leakage to one-eighth. This is evidence of the profit to be gained by extra care in making seal fits close. On the other hand, while a new piece of equipment may have a low leakage characteristic due to good fits, only a small amount of wear on rigid seal surfaces is sufficient to jump the leakage to several times the original amount, thus rendering the machine inefficient.

The length of seal *l* and the width w are comparatively insignificant alongside the clearance, since they appear to the first power only. The designer may, therefore, accept considerable compromise toward wide and short seals, so long as he can be assured of small clearance which may be maintained more or less unchanged throughout the life of the machine.

This suggests that seals should, wherever possible, be of the piston ring type. These are susceptible to extremely close initial fitting, elastically responsive to pressure differences across them for even tighter fits as pressure rises, and thereby capable of taking up wear as the machine is used.

Rings of leather and elastic plastics of various kinds have been successfully used in a number of hydraulic seals. Experiments are being carried out also at this time on low modulus elastic metals. The effective clearances obtained with such rings, allowing for surface irregularities, are of the order of several hundred-thousandths of an inch. This is to be compared with clearances over the ordinary fitted rigid piston or valve surface, the best practically attainable being of the order of several ten-thousandths of an inch.

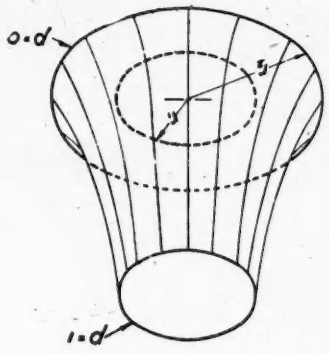


Fig. 3

Unfortunately the application of pressure - responsive seals has not been carried as far in the manufacture of moderate size piston, gear or vane units, as it has on cylinder cams, shaft closures and pipe fittings. One handicap has been the limitations of space on piston and valve surfaces, the other is the lack of proper materials to use for seal rings which will stand up under high pressures and high rubbing velocities.

The distribution of pressure in the general case of leakage through parallel surface clearances in which the parallel boundary planes have irregular shapes and in which edge effects may not be eliminated, such as in the piston or infinitely long parallel planes of constant width, is described by the differential equation

$$\frac{\partial^2 p}{\partial x^2} + \frac{\partial^2 p}{\partial y^2} = 0 \quad .. \quad .. \quad .. \quad (10)$$

where p is the pressure, and x and y the rectangular coordinates in which the leakage region is located.

Equation 10 is extremely difficult to solve for irregular boundary shapes with complicated distributions of pressure at the ends of the clearance.

A useful mental picture of pressure distribution in such cases may be obtained through the use of an analogy. Equation 10 also describes the configuration (or relative height) of a constant tension membrane which is stretched between points which have heights proportional to the values of pressure at the boundary edges of the leakage clearance. The tension membrane, such as a rubber sheet, gives an exact picture only for small deflections ; a membrane deflecting in pure shear gives an exact solution of Equation 10 for any magnitude of deflection. Fig. 3 thus shows the distribution of pressure over an annular pipe flange seal, the inner edge of which is subjected to the pipe pressure taken as 1 and the outer held to O. The distribution of pressure over the seal surface is logarithmic. The picture is useful to the designer in making his estimate of the average pressure over the surface to calculate the stresses in flange bolts, etc.

THERMAL EXPANSION OF SYNTHETICS.

By R. VIEWEG and W. SCHNEIDER. (From *Kunststoffe*, Vol. 31, No. 6, June 1941, p. 215-219)

IN the majority of cases thermal expansion measurements of synthetics is confined to a two-dimensional investigation. But the expanding number of applications of synthetics for widely varying purposes can give satisfactory results only if fuller information is available for the engineer of the effect of heat on the dimensions of the material. Hence the necessity for three-dimensional analysis of the problem.

The Measuring Apparatus.

Such measurements, without hindering the free expansion or contraction of the sample, are best carried out by means of a microscope, as shown in Fig. 1. The microscope is fitted with a rotating work table which can also be made to slide along a longitudinal and transverse axis. The total range of measurement of the instrument is 50 × 150 mms.

The main temperature range for studying the thermal expansion of synthetics is between about +20 and +150 °C. As an auxiliary to the microscope, a small oven was designed, which permits the observation of the dimensional changes taking place under the influence of temperature. Heating of the oven is controlled by means of a thermostat, connected to flexible leads, and

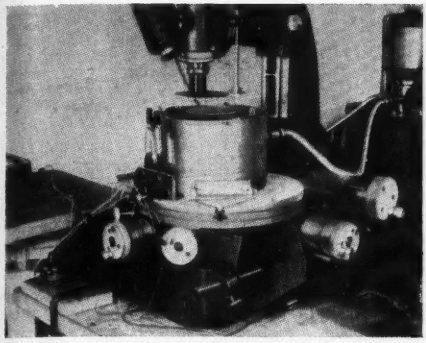


Fig. 1

the oven is basically a double walled container. The heating fluid circulates in the annulus between the two walls, and from the ambient the oven is insulated by glass silk. The top of the oven consists of a glass window, of two similar panels, through which the sample in the interior of the oven is viewed. At the beginning some difficulties were experienced owing to moisture condensing on the glass window. A drying agent placed inside the oven to absorb the water vapour did not result in great improvement, as at elevated temperatures this (phosphorus pentoxide) evaporated and condensed on the whole inner surface of the oven. A better solution was, therefore, to heat the space between the two glass panels and thus prevent condensation on the inner surface of the window. This solution contributed also, materially, in obtaining a more uniform temperature inside the oven.

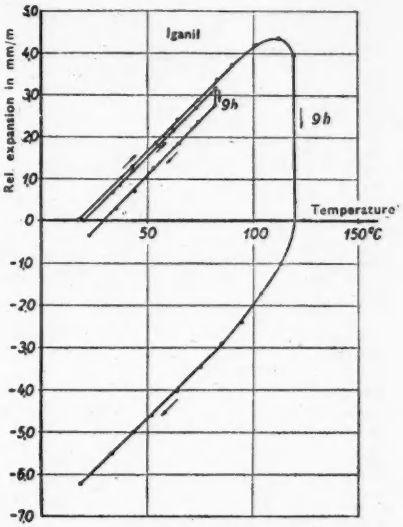


Fig. 4

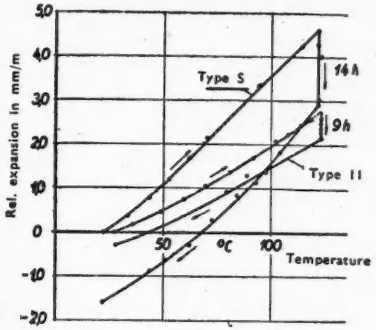


Fig. 2

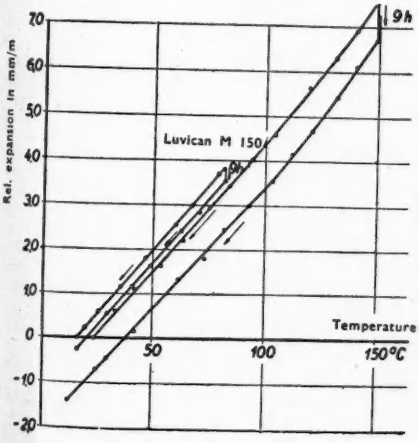


Fig. 3

To simplify measurements, scale marks were engraved by means of a razor blade on a layer of indian ink applied to the sample. This was illuminated by a lamp as shown in Fig. 1. All measurements were made at a magnification of 50×, and the accuracy of measurements was about ±0.005 mm.

Experimental Results.

The curves showing thermal expansion or contraction were established next, for various kinds of synthetics. In Fig. 2 the expansion and contraction is shown of two synthetics, Type 11 and Type S; heating of the samples took place at the respective rates of 10°/¼ hour and 10°/hour, corresponding to their respective heat conductivity. The effect of elevated temperature has resulted in the curves of familiar shape. The two sets of curves cannot be directly compared, the times of cooling being different, 14½ hours for Type S, and 9 hours for Type 11. With the latter special

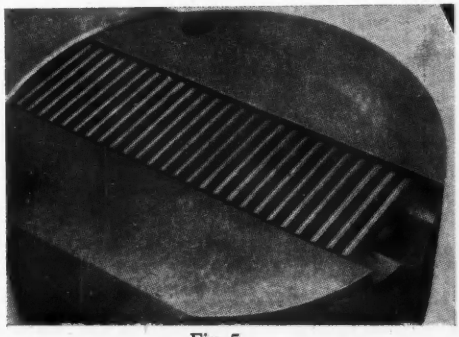


Fig. 5

attention was given to establish the range of contraction.

Fig. 3 shows typical curves for two samples of Luvican M 150, at 80° and 149° C. respectively, the duration of the contraction period being 9 hours.

In Fig. 4 curves are shown for Iganil. Contraction took place at 82° and 119° C. respectively. The small difference in the starting point of the two curves is probably due to deviations in the atmospheric temperature.

Similar tests were also made with rubber. Owing to the nature of this material, however, it had to be placed on a special table, as shown in Fig. 5, so as to permit unhindered expansion along the contacting surface. As an example, the curve showing expansion and contraction of Buna S, is given in Fig. 6. The heating period was 4 hours, the cooling period 5 hours. A noteworthy point here is the excessive expansion compared with the contraction. Similar tests were also made with natural rubber.

The expansion curve along two axes perpendicular to one another for Type S (50% Kresol) is shown in Fig. 7. Although there is a small difference noticeable being larger along a transverse axis, the difference between the two curves is very small.

In Table I the average linear expansion is given for various synthetics per °C.

These measurements have borne out one important fact: samples exposed to elevated temperatures for some time have shown when rested at room temperature subsequently, that a gradual decrease of the contraction takes place. This then suggests, that the effect of water vapour and gas emanation from the material is an important factor affecting the expansion or contraction observed.

Testing Enclosed Samples.

To investigate the effect of gas and vapour emanation, samples were tested in a completely enclosed container. Several methods were tried for this purpose until finally the following procedure was adopted. The sample was placed in a glass tube and the open end was

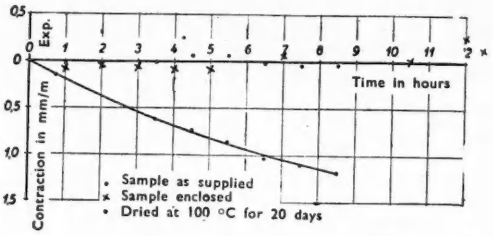


Fig. 8

then closed by a glass plate and a rubber ring and sealed with putty. The leads to the thermo-element were placed between the glass and rubber ring.

The result of such a test is shown in Fig. 8, together with the corresponding curve of a sample tested in the usual manner. While the result in atmosphere shows the familiar shape, practically no change of dimensions was noted in the case of the enclosed sample.

Experiments with Dried Samples.

From the previous test it is obvious that contraction of the material is in great part, if not entirely, due to the liberation of gas and water vapour. The water content of the material may be due to absorption from the atmosphere, or it may originate from the hardening process. According to the chemical formula, during the polycondensation, two atoms of the complex molecule of the material form a simple molecule, usually water; the remaining atoms then form a product of higher molecular weight. One product of change, i.e. usually water, will only partly leave the material, according to temperature and macromolecular conditions. A part of the water will still remain in the material as an intermolecular substance and can be driven out of the material only at elevated temperature, pressure, or by reducing the concentration.

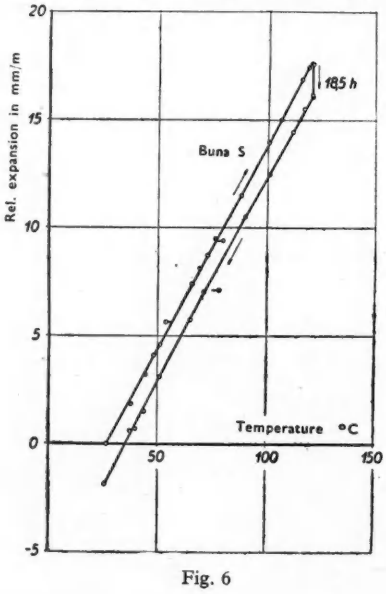


Fig. 6

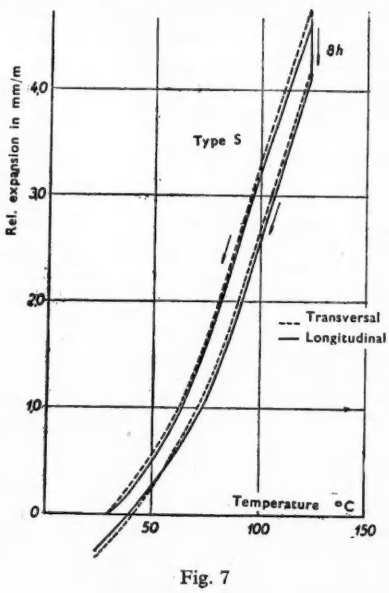


Fig. 7

This then affords a means of regulating the contraction of the material at elevated temperatures. But a heat treatment is only permissible if this does not involve a danger of subsequent absorbtion of water vapour from the atmosphere. In Fig. 8, results are also included of tests made on dried out samples. These, too, show only a slight stray along the abscissæ and again there is no appreciable change in linear dimensions.

Experiments with Surface Treated Samples.

A protective coating applied to the surface of the

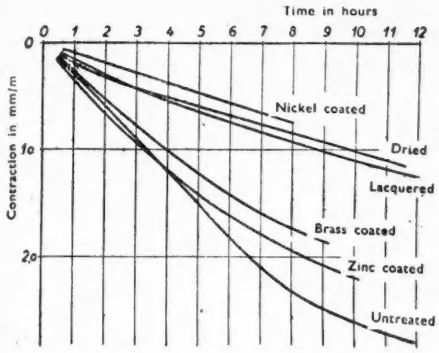


Fig. 9

synthetic might be utilised to prevent liberation of gas or water vapour. However, care must be exercised in preventing chemical attack by exposure to excessive temperature during the treatment. Experiments were subsequently made with various types of surface coating and results are shown in Fig. 9. The contraction curves correspond to a temperature of 120° C, and with the object of comparison a curve for an untreated sample is also included in the graph.

The zinc and brass coatings were applied to the surface by spraying. The lacquer coating was burnt on to the surface of the material in two stages at 180°C. (½ hour each). To study how much the drying involved with lacquering is participating in the reduction of contraction, a sample was exposed to the same heat treatment in an oven, without applying the lacquer coating to it. (Complete absence of dimensional change could not, of course, be expected in this case, as the duration of heat treatment was only ½ hour.) It can be seen from the graph, that lacquer coating did not contribute materially to the reduction of contraction, the small difference being probably due to slight differences in the heat treatments involved. Finally, nickel coating was obtained by a galvanising process, for which purpose the synthetic material was first made conductive to electricity by a coating of colloidal graphite in water.

To complete the examination, the samples were subsequently allowed to remain at room temperature with a relative humidity of 50% and their weight-time curve established (i.e. their absorption of water vapour). The result is shown in Fig. 10. As would be expected, the smallest increase in weight was recorded with the nickel coated specimen and the largest with the dried uncoated sample. The lacquer coating inhibits water absorption only to a slight degree.

Volumetric Changes.

The method of measuring linear changes of dimension does not permit simultaneous measurement along the third co-ordinate; it would not be of

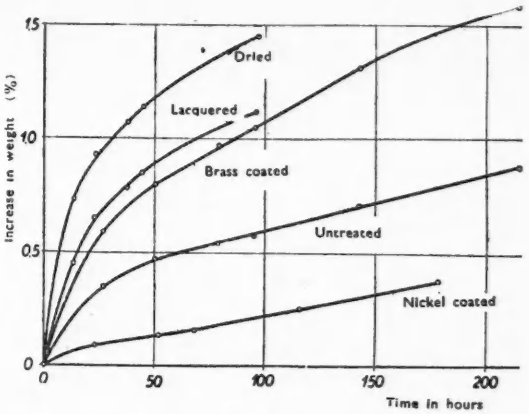


Fig. 10

sufficient accuracy. Therefore, the volumetric change was separately determined by the water immersion method, which is not objectionable, provided the duration of immersion is short.

Basically different is the behaviour of thermoplastic materials as was found from tests with Trolitul and Benzyl-cellulose. The sample bars of 55 ×

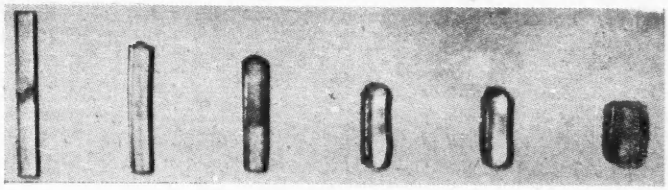


Fig. 11

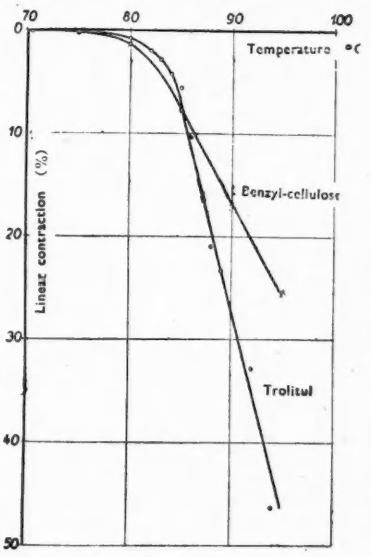


Fig. 12

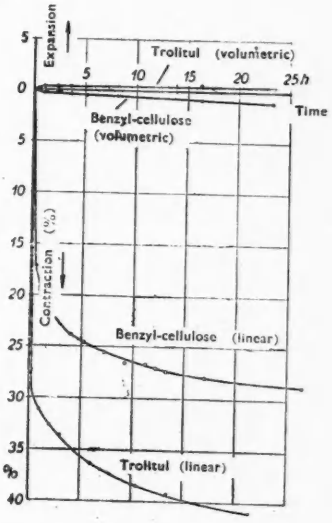


Fig. 13

6×4 mm^3 dimensions, have shown considerable change in linear dimensions, but without loss of weight. It has been known for a long time already that Trolitul is very stable against effects of moisture. It was often observed that Trolitul shows considerable shrinkage when exposed for a longer period to elevated temperature but this was always accompanied by an expansion along the other two axes. (See Fig. 11). Samples of Trolitul and Benzyl cellulose were placed in an oven and dried for two hours and then the contraction observed. The results are shown in Fig. 12, each point on the graph corresponding to a separate sample. For both materials the marked change in linear dimensions starts at about 80° C.

The contraction was found, however, to be confined to one axis only, a simultaneous expansion along the other two axes taking place (Fig. 13). The samples heated at 100° C were withdrawn from the oven from time to time and allowed to cool down. The volume was then measured at room temperature, showing that there was no volumetric change taking place, as a matter of fact with Trolitul even a slight increase in volume could be observed.

TABLE I.

Material.	Mean linear expansion in °C. × 10^6.	Temperature range °C.
Type S (50 % Kresol),[1]	50	30 to 120
Type 11,[2]	29	25 to 120
Cardboard	17	20 to 70
Natural hard Rubber I	140	20 to 120
Natural hard Rubber II	195	20 to 120
Buna S I,[3]	185	20 to 120
Buna S II,[3]	120	20 to 120
Perbunan,[3]	130	20 to 120
Iganil, [4]	50	20 to 100
Luvican M 150,[5] ..	57	20 to 100
Trolitul,[6]	90	25 to 60

[1] Phenolic (or cresolic) resin filler : wood flour (Standard general purpose moulding powder).
[2] Phenolic (or cresolic) resin filler : mineral.
[3] Synthetic rubber (made from Butadiën).
[4] Aniline—formaldehyde resin.
[5] Polyvinyl—carbasol with improved heat resistance.
[6] Polystrol resin.

"PURGING" CONTROLLED ATMOSPHERE FURNACES.

By F. B. LESLIE. (From *Metals and Alloys*, Vol. 16, No. 2, pp. 241–245, August, 1942.)

EVERYONE associated with the operation of pit or bell type furnaces using controlled atmospheres rich in hydrogen and carbon monoxide recognises the ever-attendant danger of explosion as a result of improper purging. Only after a serious accident do many of us understand how real this danger is.

Furnace builders and users alike have evolved operating procedures intended to overcome this hazard the usual practice requiring that the furnace be purged for a specified period of time. The best laid plans can, however, go astray because of variations in size or location of charge or through a simple oversight, such as a partly opened purge line valve. The result is an incomplete air removal and the formation of an explosive mixture. It should be noted that at the start of the purge the furnace contents are not explosive because the concentration of combustible gases is below the lower explosive limit. As purging progresses, however, the lower explosive limit is reached and the hazard is present until the combustible gas content exceeds the higher explosive limit.

To the best of the author's knowledge instruments have not been used so far for the determination of safe conditions being established. However, many engineers are giving increased attention to gas analysis equipment in this connection, and it is likely that others will be interested in knowing of recent developments.

The Explosion Gases and Their Densities.

The dangerous constituents in commercial atmospheres are hydrogen, carbon monoxide and methane, the latter as a rule being present in low concentration. The remaining gases are usually carbon dioxide and nitrogen which, being inert, act as diluents. The specific gravity of the explosive gases is less than 1.0 (air). When the controlled atmosphere contains sufficient combustible gases to impart explosive possibilities, it will also be found that their presence causes the overall specific gravity of the atmosphere to be less than 1.0. To illustrate this statement consider the typical atmosphere given in Table I.

Since the relative density of air and the atmosphere gas differ, it is possible to measure the proportions of

TABLE I.

Atmosphere Type	*Composition, per cent* CO2	CO	H2	CH4	N2	*Specific Gravity*
Incomplete combustion	6.0	9.6	10.3	0.5	73.6	0.913
Incomplete combustion + secondary cracking	2.0	16.2	23.8	0.7	57.3	0.765
Catalytic cracking	1.1	18.2	34.6	0.6	45.5	0.663
Dissociated NH3	..	..	75.0	..	25.0	0.294
30% Dissociated NH3	..	..	22.5	70.0 NH3	7.5	0.504

air in the furnace gases by comparing the specific gravity of the outlet mixture with the specific gravity of the atmosphere gas entering the furnace. As an example, if an atmosphere gas of 0.80 specific gravity is admitted to a furnace and the specific gravity of the outlet gases is 0.90, it may be concluded that the mixture is half air and half atmosphere gas. If on the other hand the specific gravity was measured and found to be 0.80, the gas no longer contains air and the furnace has been completely purged.

Some furnaces are double-purged, first with an inert gas and subsequently with the controlled atmosphere gas, the purpose being to remove all oxygen before introducing combustible gases. The inert gas is commonly prepared by burning fuel gas with the theoretical air supply, the specific gravity of which is above 1.0. The specific gravity of the outlet mixture may be used to indicate when complete air removal has been effected and also for the second purge to indicate when the controlled atmosphere has completely removed the inert purging gas.

Safe Purging.

One method of testing for safe purging therefore resolves itself into measuring the specific gravity of the outlet gases and continuing the purge until the specific gravity of the pure atmosphere gas is reached. To illustrate this, Fig. 1 was prepared from data obtained on an electrically heated Bell furnace. Before using the specific gravity measurement as a check on operation, the standard practice had been to purge this furnace for an hour and a half. Some portion of this period

was provided to allow for uncertainties. However, it can be observed that nearly an hour of valuable time was wasted, as purging was almost complete after 40 minutes.

It should not be misunderstood that the minimum safe purging time can be determined once and then repeated as a standard rule, but rather that the specific gravity should be measured during every purge. The operator will then know on every heat when complete purging has been effected and thus accomplish the time saving without risk of explosion.

Measuring Atmosphere Quality.

In addition to safety, which is of paramount importance, the measurement of specific gravity may be also used in the preparation of the atmosphere gas to assist in maintaining uniform composition, thereby improving the quality of the product being heat-treated.

The meaning of specific gravity when applied on some of the popular atmosphere either for determining safe purging or checking atmosphere uniformity in production, is described in the following paragraphs.

"*Incomplete Combustion*" *Atmospheres.*—When a fuel gas is burned with less air than is needed for complete combustion, the resulting atmosphere usually contains carbon dioxide, carbon monoxide, methane, hydrogen and nitrogen. The analysis depends on many factors, but mostly upon the air/gas ratio. When this ratio is relatively high, the gas contains a large percentage of carbon dioxide and small amounts of carbon monoxide, methane and hydrogen. The gas has a comparatively high specific gravity because of the high carbon dioxide content. With lower air/gas ratios the carbon dioxide decreases and the specific gravity becomes lower because of the increased hydrogen content. It is, therefore, possible to maintain the correct ratio by measuring the specific gravity of the combustion products. Variations in specific gravity and composition of the raw gas, variations in humidity of gas or air and variations in humidity of gas or air and in termperature or pressure may thus be compensated for by adjusting the combustion equipment to produce an atmosphere of constant specific gravity. Variations of 0.1–0.2% carbon dioxide and even smaller variations of carbon monoxide and hydrogen

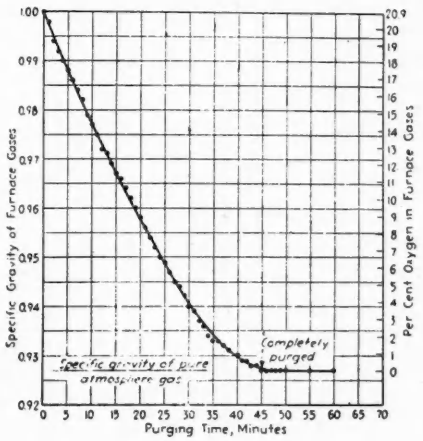

Specific Gravity of Furnace Gases
Per Cent Oxygen in Furnace Gases
Purging Time, Minutes
Completely purged
Specific gravity of pure atmosphere gas

Fig. 1. Charge: 13,500 lbs. of coiled strip steel. Fan running.

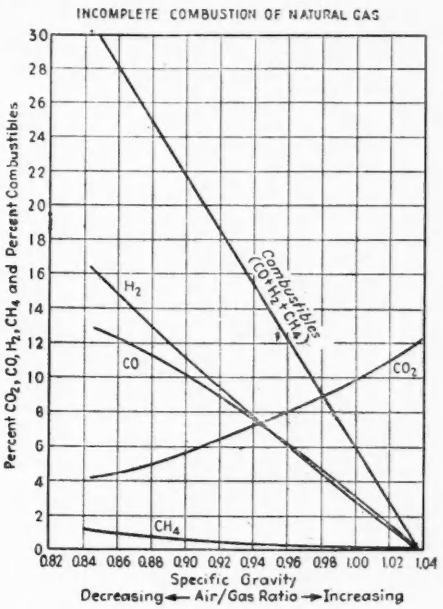


Fig. 2

may be readily detected by the specific gravity measurement.

In Fig. 2 the relation between the composition and specific gravity of the atmosphere of a normalising furnace is shown. From this it becomes clear why measurement of the specific gravity gives the necessary information on the analyses of the atmosphere gas. It is not necessary, however, to prepare such a chart because with only little experience the operators will learn that a particular specific gravity corresponds to the desired atmosphere composition and it then becomes a simple matter to hold the analysis constant or reproduce it at any time.

Incomplete Combustion eth Carbon Dioxide Removal.—Some atmospheres are produced by incomplete combustion followed by removal of the carbon dioxide through chemical absorption or converting carbon dioxide to carbon monoxide by passing the gas through incandescent charcoal. By sampling the generator gas, the air/gas ratio may be verified and by sampling the finished gas, the completeness of carbon dioxide removal or conversion may be investigated.

Unburned Air-Gas Mixtures.—At times it is desirable or necessary to measure the air/gas ratio before combustion and this may be done by measuring the specific gravity of the unburned mixture. For example, the correct specific gravity when 3½ parts of air are mixed with one part of gas of 0.64 specific gravity is calculated to be 0.92 as follows:

Gas	1 part	× 0.64	= 0.64
Air	3½ parts	× 1.00	= 3.50
Mixture	4½ parts		= 4.14

$$\text{Sp. gr.} = \frac{4.14}{4.50} = 0.92$$

A higher ratio will be indicated by an increase in specific gravity and conversely, a lower ratio by a decrease in specific gravity.

Catalytic Cracking.—When a gas is burned with a very marked deficiency of air, in the presence of a catalyst the atmosphere produced is rich in hydrogen and carbon monoxide and contains very little carbon dioxide. The specific gravity will be very low because of the abundance of hydrogen. If improper operating conditions prevail the gas will contain too much carbon dioxide and too little carbon monoxide and hydrogen and the specific gravity will increase. To ascertain the proportion of air and gas entering the cracking unit, the specific gravity of their mixture should be measured.

Dissociated Ammonia.—If ammonia vapour is heated to about 1,600°F. it cracks to produce an atmosphere of 75% hydrogen and 25% nitrogen. The raw ammonia has a specific gravity of 0.595 and the completely dissociated mixture a specific gravity of 0.295. It is therefor, apparent that a high specific gravity indicated incomplete dissociation. Should a partly dissociated mixture be desired, the specific gravity may be used to measure the extent of cracking.

Improving Economy.

Another important use for specific gravity measurement concerns fuel economy in gas heated furnaces such as those using radiant tubes. The combustion is carried out with an excess of air and the combustion products contain carbon dioxide, oxygen and nitrogen. When too much air is supplied a large amount of heat is wasted in the large volume of flue gases which leave at relatively high temperature. At the same time the carbon dioxide is low because of dilution by the excess air. As the air supply is reduced the heat loss diminishes and the carbon dioxide increases. The specific gravity gradually increases until it reaches a maximum with the theoretically correct air supply. Should the air supply become deficient free hydrogen will appear in the combustion gases and cause a sharp drop in the specific gravity. Thus to obtain maximum combustion

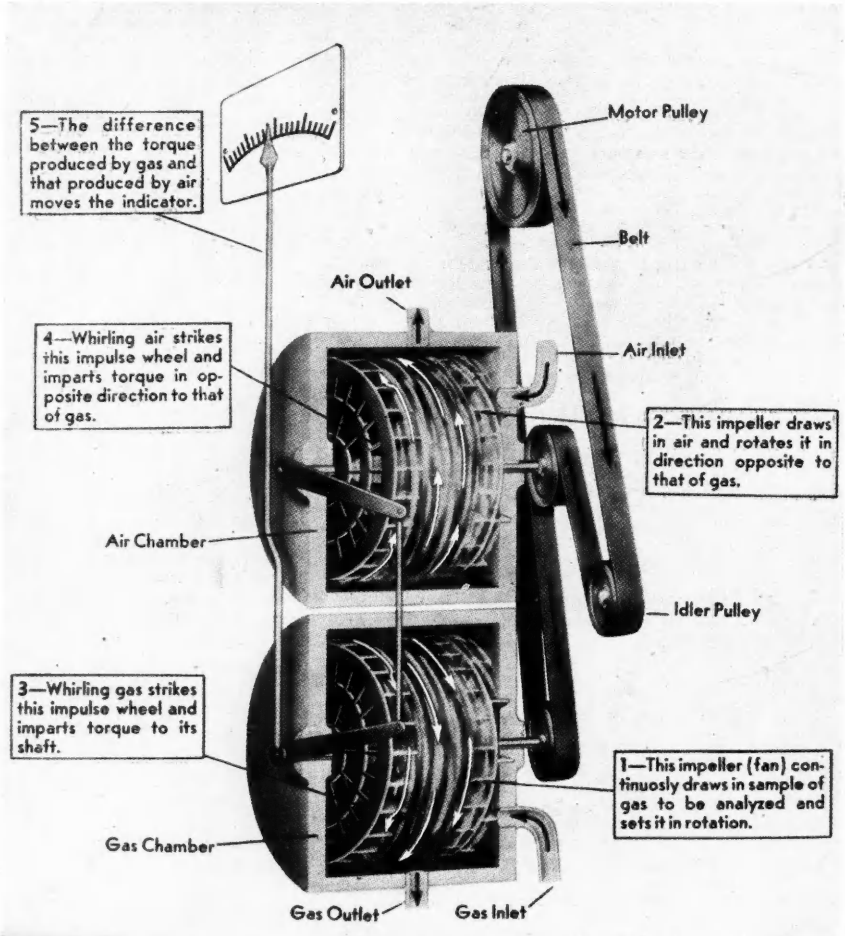

5—The difference between the torque produced by gas and that produced by air moves the indicator.
Motor Pulley
Belt
Air Outlet
4—Whirling air strikes this impulse wheel and imparts torque in opposite direction to that of gas.
Air Inlet
2—This impeller draws in air and rotates it in direction opposite to that of gas.
Air Chamber
Idler Pulley
3—Whirling gas strikes this impulse wheel and imparts torque to its shaft.
1—This impeller (fan) continuosly draws in sample of gas to be analyzed and sets it in rotation.
Gas Chamber
Gas Outlet
Gas Inlet

Fig. 3

efficiency it is only necessary to adjust the burners to produce flue gases of the highest specific gravity.

The Measuring Instrument.

A simple automatic instrument for measuring the specific gravity of gases is shown in phantom in Fig. 3, and is known commercially as the Ranrex furnace atmosphere analyser.

The lower impeller draws in a sample of the gas being tested, sets it in rotation and creates a torque on its companion impulse wheel located in the same chamber. This torque, which is proportional to the gas density, is compared with the torque produced by atmospheric air in an identical upper chamber, the impeller of which rotates in the opposite direction. The difference between these opposing torques is a measure of the specific gravity and causes the pointer to move over the scale. The gas and air sample are brought to the same temperature and humidity by a humidifier, eliminating possibility of error from those sources.

The gas sample passes continuously through the instrument at a high rate of flow and since no time is required for chemical reaction, the instrument responds almost instantaneously.

COMPOSITION AS A MEASURE OF THE TENSILE STRENGTH OF CAST IRON.

By AUGUST GIMMY. (From *Die Giesserei*, Vol. 29, No. 13, 26th June, 1942, pp. 226-230.)

THE most inportant alloying elements in cast-iron are carbon and silicon. For a long time it had been thought that the sum C + Si would be a criterion for the mechanical properties of cast-iron; unfortunately, however, this has not been the case.

Much valuable research with the object of finding a relationship between C, Si and the mechanical properties of cast-iron, had little or no result. On the other hand the line of demarcation between white and grey solidification seems to depend upon C and Si but, even so, considerable discrepancies arise depending on the method of melting and other factors.

According to Osann, for obtaining the eutectic and pearlitic structures, 0.1 % C. is equivalent to 0.2 % Si, so that the structure depends on the factor C + ½Si. The eutectic amounts of carbon and silicon, as shown in Table I, occur when C + ½Si = 3.9, for a wall thickness of 50 mm. A larger value of C + ½Si would give a hypereutectic, and a smaller value a hypoeutectic structure.

TABLE 1. Eutectic carbon and silicon contents for a cylinder thickness as suggested by Osann.

C %	Si %	C %	Si %	C %	Si %	C %	Si %
2,5	2,8	2,8	2,2	3,1	1,6	3,4	1,0
2,6	2,6	2,9	2,0	3,2	1,4	3,5	0,8
2,7	2,4	3,0	1,8	3,3	1,2	3,6	0,6
						3,7	0,4

The hypothesis put forward by Osann may be considered as a big step forward, because it no longer deals with the sum C + Si as a guide to the tensile strength, although too much stress is still laid on the influence of silicon. For instance, in Table I, eutectic carbon and silicon content is shown as 2.5 % C and 2.8 % Si, and 3.5 % C and 0.8 % Si. In both cases the sum C + ½Si = 3.9 % is obtained. Thus according to Osann, the 50 mm. thickness would have a eutectic structure and a tensile strength of σ = 24 kg/mm.², which in reality is not the case.

The " degree of saturation " $S_c = \dfrac{\%\ C}{4.23 - \%\ Si/3.2}$

which was developed in 1910 by Heyn and corrected by H. Hanemann and A. Schrader, has been wrongly neglected. One reason for this neglect might be the complicated method of calculation as compared to the sum C + Si, but the introduction of tables would greatly facilitate the use of the S_c values. If, according to Osann, the assumption that two parts silicon could replace one part of carbon were correct, the above mentioned eutectic carbon and silicon contents of 2.5 % C and 2.8 % Si on the one hand and 3.5 % C and 0.8 % Si on the other hand, would give equal strength. The fact that a purely pearlite structure of cast-iron containing 3.5 % C is 60 % richer in graphite than cast-iron of 2.5 % C content, makes the assumption appear improbable. If for both cases the saturation, S_c, were calculated, it would be found that the former gives a value of 0.88 and the latter 0.75, showing that there really is a large variation in the two types.

Fig. 1 shows the lines of equal saturation and tensile strength in the " Maurer Diagram."

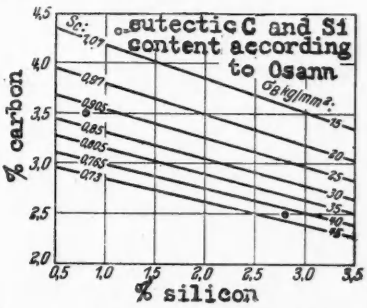


Fig. 1

According to this, the cast-iron of lower carbon content and a value of S_c = 0.75 would, in a 30 mm. round bar, have a tensile strength of σ_b = 42 kg/mm.² whereas the cast-iron of higher carbon content and a value of S_c = 0.88 would give σ_b = 27 kg/mm.²

At this point Fig. 1 will be used to consider the variable influence of carbon and silicon on the tensile strength of cast-iron. The silicon content was therefore read off at the intersection of the lines of equal carbon content with the lines of equal saturation and tensile strength. The readings were checked according to the formula $Si = (4.23 - \dfrac{C}{S_c})\ 3.2.$

Similarly the carbon content was read off at the intersection of the lines of equal silicon content with the lines of equal saturation and tensile strength. The readings were checked according to the formula

$$C = (4.23 - \frac{Si}{3.2})\ S_c$$

In Table 2 the decrease in tensile strength with 0.1 % increase of silicon at constant carbon content has been calculated, whereas in Table 3 the decrease in

tensile strength with 0.1 % increase of carbon at constant silicon content was worked out. From Table 2 it becomes obvious that the decrease in tensile strength varies between 0.90 kg/mm.² and 0.45 kg/mm.² per 0.1 % increase in silicon, and the percentage decrease of tensile strength varies between 1.97 and 2.6%. The decrease of tensile strength for constant silicon and increasing carbon content is, however, greater (as shown in Table 3) and varies between 1.93 and 4.16 kg/mm.² i.e., 7.66 and 9.6%, averaging 8.67% per 0.1 % increase of carbon.

It is important to note that according to this diagram 0.1 % silicon changes the tensile strength by 2.25%, and 0.1 % carbon by 8.67%. As 2.25/8.67 = 1/3.8, it follows that, as far as influence on tensile strength is concerned, one part carbon is equivalent to 3.8 parts silicon. As mentioned above, the method of calculating the saturation is somewhat complicated. The formula developed and used by Piwowarsky is, however, very simple being $3 + \frac{1}{3}$ Si.

In order to find the relationship between C + 1/3 Si and the Sc value, the author has' calculated the Sc values and the relation of the Sc value to C + 1/3 Si for the most common cast-irons having silicon contents of 0.6 to 3.4% and carbon contents of 2.6 to 3.6%, and has shown that the discrepancies are low.

The calculations were carried out as follows : The Sc values were first calculated for the carbon and silicon contents shown in Table 4 C + 1/3 Si (column 3) was then divided by the Sc value. These ratios (column 4) vary between 4.26 and 4.56 for the various

TABLE 2. Decrease of tensile strength with increasing silicon content, carbon content remaining constant.

C %	Si %	Saturation S_c	Tensile strength σ_B kg/mm²	Decrease of tensile strength 0,1% Si kg/mm²	%
2,75	1,48	0,730	45	—	—
2,75	2,03	0,765	40	0,90	2,00
2,75	2,60	0,805	35	0,79	1,97
2,75	3,18	0,850	30	0,86	2,46
3,00	0,99	0,765	40	—	—
3,00	1,61	0,805	35	0,80	2,00
3,00	2,24	0,850	30	0,79	2,26
3,00	2,93	0,905	25	0,72	2,40
3,25	0,62	0,805	35	—	—
3,25	1,31	0,850	30	0,72	2,06
3,25	2,04	0,905	25	0,68	2,26
3,25	2,81	0,970	20	0,65	2,60
3,50	1,15	0,905	25	—	—
3,50	1,99	0,970	20	0,60	2,40
3,50	3,07	1,070	15	0,47	2,35
3,75	1,16	0,970	20	—	—
3,75	2,32	1,070	15	0,45	2,25
Mean decrease of tensile strength per 0,1% Si = Increase				0,70	2,25

TABLE 3. Decrease of tensile strength with increasing carbon content, silicon content remaining constant.

C %	Si %	Saturation S_c	Tensile strength σ_B kg/mm²	Decrease of tensile strength 0,1% C kg/mm²	%
2,86	1,0	0,730	45	—	—
3,00	1,0	0,765	40	3,57	7,93
3,15	1,0	0,805	35	3,33	8,32
3,33	1,0	0,850	30	2,77	7,91
3,54	1,0	0,905	25	2,63	8,77
3,80	1,0	0,970	20	1,92	7,66
2,74	1,5	0,730	45	—	—
2,88	1,5	0,765	40	3,57	7,93
3,03	1,5	0,805	35	3,33	8,32
3,20	1,5	0,850	30	2,94	8,40
3,40	1,5	0,905	25	2,50	8,33
3,66	1,5	0,970	20	2,08	8,32
2,63	2,0	0,730	45	—	—
2,76	2,0	0,765	40	3,84	8,53
2,90	2,0	0,805	35	3,57	8,92
3,06	2,0	0,850	30	3,12	8,91
3,26	2,0	0,905	25	2,50	8,33
3,50	2,0	0,970	20	1,92	7,68
2,52	2,5	0,730	45	—	—
2,64	2,5	0,765	40	4,16	9,24
2,78	2,5	0,805	35	3,57	8,92
2,93	2,5	0,850	30	3,33	9,51
3,12	2,5	0,905	25	2,63	8,76
3,34	2,5	0,970	20	2,27	9,08
2,40	3,0	0,730	45	—	—
2,52	3,0	0,765	40	4,16	9,24
2,65	3,0	0,805	35	3,84	9,60
2,80	3,0	0,850	30	3,33	9,51
2,98	3,0	0,905	25	2,77	9,23
3,19	3,0	0,970	20	2,38	9,52
Mean decrease of tensile strength per 0,1% C = Increase				3,04	8,67

TABLE 4. The relation of the sum C + 1/3 Si to the saturation S_c.

C %	Si %	Saturation S_c	C+1/3 Si	C+1/3 Si / S_c	C+1/3 Si / 4,38	Discrepancies from the S_c value	%
1		2	3	4	5	6	7
2,6	1,4	0,685	3,067	4,48	0,700	+0,015	2,2
2,6	1,8	0,709	3,200	4,51	0,730	+0,021	3,0
2,6	2,2	0,734	3,333	4,54	0,761	+0,027	3,7
2,6	2,6	0,761	3,467	4,55	0,791	+0,030	3,9
2,6	3,0	0,790	3,600	4,56	0,822	+0,032	4,0
2,6	3,4	0,821	3,733	4,55	0,852	+0,031	3,8
2,8	1,2	0,727	3,200	4,40	0,730	+0,003	0,4
2,8	1,6	0,750	3,333	4,44	0,761	+0,011	1,5
2,8	2,0	0,777	3,467	4,46	0,791	+0,014	1,8
2,8	2,4	0,804	3,600	4,48	0,822	+0,018	2,2
2,8	2,8	0,835	3,733	4,47	0,852	+0,017	2,0
2,8	3,2	0,867	3,867	4,46	0,882	+0,015	1,7
3,0	1,0	0,766	3,333	4,35	0,761	—0,005	0,6
3,0	1,4	0,791	3,467	4,38	0,791	—	—
3,0	1,8	0,818	3,600	4,40	0,822	+0,004	0,5
3,0	2,2	0,846	3,733	4,41	0,852	+0,006	0,7
3,0	2,6	0,878	3,867	4,40	0,882	+0,004	0,5
3,0	3,0	0,910	4,000	4,40	0,913	+0,003	0,3
3,2	0,8	0,804	3,467	4,31	0,791	—0,013	1,6
3,2	1,2	0,830	3,600	4,34	0,822	—0,008	1,0
3,2	1,6	0,858	3,733	4,35	0,852	—0,006	0,7
3,2	2,0	0,887	3,867	4,36	0,882	—0,005	0,6
3,2	2,4	0,919	4,000	4,35	0,913	—0,006	0,7
3,2	2,8	0,953	4,133	4,34	0,944	—0,009	0,9
3,4	0,6	0,841	3,600	4,28	0,822	—0,019	2,3
3,4	1,0	0,868	3,733	4,30	0,852	—0,016	1,8
3,4	1,4	0,896	3,867	4,31	0,882	—0,014	1,6
3,4	1,8	0,927	4,000	4,31	0,913	—0,014	1,5
3,4	2,2	0,959	4,133	4,31	0,944	—0,015	1,6
3,4	2,6	0,994	4,267	4,29	0,974	—0,020	2,0
3,6	0,6	0,890	3,800	4,27	0,868	—0,022	2,5
3,6	1,0	0,919	3,933	4,28	0,898	—0,021	2,3
3,6	1,4	0,949	4,067	4,28	0,928	—0,021	2,2
3,6	1,8	0,982	4,200	4,28	0,959	—0,023	2,3
3,6	2,2	1,016	4,333	4,26	0,989	—0,027	2,7

C + ⅓Si values. To determine the discrepancies, C + Si was divided by the mean value, i.e. 4.38 (column 5). The discrepancies as shown in columns 6 and 7 are very low, particularly in the region of the 3.0 to 3.2% carbon content, which is the most common, where they are between 0 and 0.013 and are thus less than 1% with the exception of two values. At 2.6 to 2.8% carbon content the discrepancies vary between +0.003 and +0.032 and at higher carbon content between −0.014 and −0.027. The percentage discrepancies, however, are low varying from 4% at 2.8% to 2.6% carbon to 2.7% at 3.4% to 3.6% carbon.

Despite these low values the author has tried to find an even better relationship, and therefore suggests the sum C + 0.3 Si. Though at first sight there seems little to warrant such a suggestion, closer study reveals the reason.

Table 5 shows the same working for the same carbon and silicon contents as Table 4, columns 3 to 7 showing the sum C + 0.3 Si and the relation to the Sc value as well as the discrepancies. As shown in column 4, the ratio varies between 4.19 and 4.44 which is a slight reduction. Thus the mean is only 4.31, and it follows that the discrepancies (columns 6 and 7) which are based on this mean value, are also lower. They vary between 0 to 0.028, being only 3% in the worst case.

TABLE 5. The relation of the sum C + 0.3 Si to the saturation S_c.

C %	Si %	Saturation S_c	C+0,3 Si	$\frac{C+0,3\ Si}{S_c}$	$\frac{C+0,3\ Si}{4,31}$	Discrepancies from the Sc value	%
1		2	3	4	5	6	7
2,6	1,4	0,685	3,02	4,41	0,700	+0,015	2,2
2,6	1,8	0,709	3,14	4,43	0,728	+0,019	2,7
2,6	2,2	0,734	3,26	4,44	0,756	+0,022	3,0
2,6	2,6	0,761	3,38	4,44	0,784	+0,023	3,0
2,6	3,0	0,790	3,50	4,43	0,812	+0,022	2,8
2,6	3,4	0,821	3,62	4,41	0,840	+0,019	2,3
2,8	1,2	0,727	3,16	4,35	0,733	+0,006	0,8
2,8	1,6	0,750	3,28	4,37	0,761	+0,011	1,5
2,8	2,0	0,777	3,40	4,37	0,789	+0,012	1,6
2,8	2,4	0,804	3,52	4,38	0,817	+0,013	1,6
2,8	2,8	0,835	3,64	4,36	0,844	+0,009	1,1
2,8	3,2	0,867	3,76	4,33	0,872	+0,005	0,6
3,0	1,0	0,766	3,30	4,31	0,766	—	—
3,0	1,4	0,791	3,42	4,32	0,792	+0,001	0,1
3,0	1,8	0,818	3,54	4,33	0,821	+0,003	0,4
3,0	2,2	0,846	3,66	4,33	0,849	+0,003	0,4
3,0	2,6	0,878	3,78	4,30	0,877	—0,004	0,1
3,0	3,0	0,910	3,90	4,29	0,905	—0,005	0,5
3,2	0,8	0,804	3,44	4,28	0,798	—0,006	0,7
3,2	1,2	0,830	3,56	4,29	0,826	—0,004	0,5
3,2	1,6	0,858	3,68	4,29	0,854	—0,004	0,5
3,2	2,0	0,887	3,80	4,28	0,882	—0,005	0,6
3,2	2,4	0,919	3,92	4,26	0,910	—0,009	1,0
3,2	2,8	0,953	4,04	4,24	0,937	—0,016	1,7
3,4	0,6	0,841	3,58	4,26	0,831	—0,010	1,2
3,4	1,0	0,868	3,70	4,26	0,858	—0,010	1,2
3,4	1,4	0,896	3,82	4,26	0,886	—0,010	1,1
3,4	1,8	0,927	3,94	4,25	0,914	—0,013	1,4
3,4	2,2	0,959	4,06	4,23	0,942	—0,017	1,8
3,4	2,6	0,994	4,18	4,20	0,970	—0,024	2,4
3,6	0,6	0,890	3,78	4,25	0,877	—0,013	1,5
3,6	1,0	0,919	3,90	4,24	0,905	—0,014	1,5
3,6	1,4	0,949	4,02	4,23	0,932	—0,017	1,8
3,6	1,8	0.982	4,14	4,22	0,961	—0,021	2,1
3,6	2,2	1,016	4,26	4,19	0,988	—0,028	2,7

TABLE 6. Quick method of calculating the saturation.

C %	Si %	Saturation S_c	$S_c = \frac{C+{}^1/_4\ Si}{4} - 0,04$	Discrepancies from the S_c value	%
1		2	3	4	5
2,6	1,4	0,685	0,697	+0,012	1,7
2,6	1,8	0,709	0,722	+0,013	1,8
2,6	2,2	0,734	0,747	+0,013	1,8
2,6	2,6	0,761	0,772	+0,011	1,4
2,6	3,0	0,790	0,797	+0,007	0.9
2,8	3,4	0,821	0,822	+0,001	0,1
2,8	1,2	0,727	0,735	+0,008	1,1
2,8	1,6	0,750	0,760	+0,010	1,1
2,8	2,0	0,777	0,785	+0,008	1,0
2,8	2,4	0,804	0,810	+0,006	0,7
2,8	2,8	0,835	0,835	—	—
3,0	3,2	0,867	0,860	—0,007	0,8
3,0	1,0	0,765	0,772	+0,007	0,9
3,0	1,4	0,791	0,797	+0,006	0,8
3,0	1,8	0,818	0,822	+0,004	0,5
3,0	2,2	0,846	0,847	+0,001	0,1
3,0	2,6	0,878	0,872	—0,006	0,7
3,2	3,0	0,910	0,897	—0,013	1,4
3,2	0,8	0,804	0,810	+0,006	0,7
3,2	1,2	0,830	0,835	+0,005	0,6
3,2	1,6	0,858	0,860	+0,002	0,2
3,2	2,0	0,887	0,885	—0,002	0,2
3,2	2,4	0,919	0,910	—0,009	1,0
3,4	2,8	0,953	0,935	—0,018	2,0
3,4	0,6	0,841	0,847	+0,006	0,7
3,4	1,0	0,868	0,872	+0,004	0,5
3,4	1,4	0,896	0,897	+0,001	0,1
3,4	1,8	0,927	0,922	—0,005	0,5
3,4	2,2	0,959	0,947	—0,012	1,2
3,6	2,6	0,994	0,972	—0,022	2,2
3,6	0,6	0,890	0,897	+0,007	0,8
3,6	1,0	0,919	0,922	+0,003	0,3
3,6	1,4	0,949	0,947	—0,002	0,2
3,6	1,8	0,982	0,972	—0,010	1,0
2,6	2,2	1,016	0,997	—0,019	1,9

The following example bears out the better relation of C + 0.3 Si to the Sc value. According to Table 4 two samples of cast-iron of 2.6% carbon and 3.0% silicon on the one hand, and 3.4% carbon and 0.6% silicon on the other having Sc values of 0.79 and 0.84, both give the sum C + ⅓ Si as 3.6, whereas the sum C + 0.3 Si gives 3.5 in the former case and 3.58 in the latter, and thus at least points towards a difference in the S_c values.

Some slight advantage in using C + 0.3 Si might be gained owing to the fact that it is easier to multiply by 0.3 than divide by 3, particularly in mental arithmetic.

The author has shown that both C + ⅓ Si and C + 0.3 Si fulfil the practical requirements and may conveniently be substituted for the Sc value. As far as their influence on tensile strength is concerned, three parts of silicon are roughly equivalent to one part of carbon.

It now would be desirable to alter manufacturers' specifications to conform to this conclusion, and thereby giving the foundries somewhat more clearly defined limits. Considerations of machining and reduction of porosity would remain unaltered problems.

XUM

Though the sum $C + 0.3\,Si$ is sufficient for all practical purposes the author has developed a formula that can be easily remembered for carbon contents of 2.6 to 3.6%, and silicon contents of 0.6 to 3.4%. The formula contains nothing, but the number 4 apart from C and Si and reads

$$S_c = \frac{C + \frac{1}{4}\,S_c}{4} - 0.04$$

Column 3 Table 6 shows the Sc values worked out by this formula, and as shown in columns 4 and 5, the discrepancies are extremely low, varying between 0 and 2.2%.

THERMOSTATING FOR COMFORT.

By E. E. LYNCH, Westlynn Works, General Electric Co. (From *General Electric Review*, Vol. 45, No. 7, pp. 393–397, July, 1942.)

THE domestic thermostat must be more than merely a sensitive temperature responsive device in order to provide the greatest degree of comfort possible. Many variables influence the performance of a thermostat. It may be applied to control a warm-air unit, a steam boiler system or a hot water system, with or without forced circulation, in a house that is well insulated or poorly insulated, and that has excessive heating capacity or barely enough. Modern thermostats are equipped with an adjustible "comfort dial" to "tune" it to the operating conditions, under which it must operate.

A distinctive feature of the modern thermostat shown in Fig. 1 is the straight instead of a curved bimetal blade which, because of its thinness is quick to respond to temperature changes. The figure shows the attractive external appearance of the textilite plastic casing. The plastic base is separated from the wall by proper air-space with the effect, that the thermostat responds more to air temperature and less to wall temperature. Many other improvements have been achieved in other parts of these new thermostats.

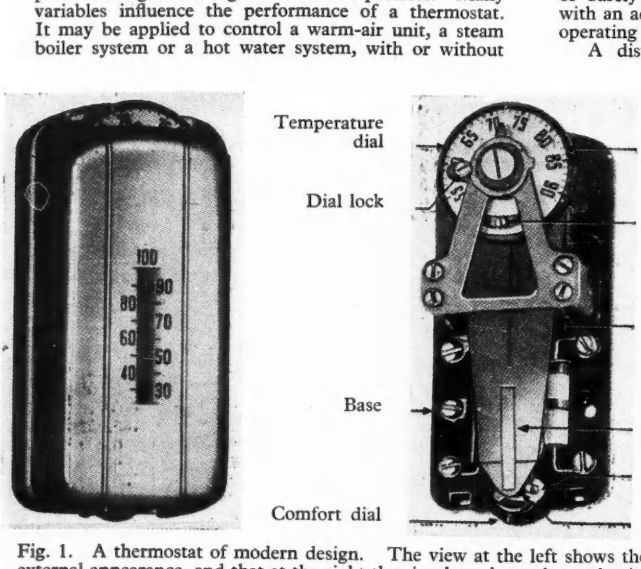


Fig. 1. A thermostat of modern design. The view at the left shows the attractive external appearance, and that at the right the simple and sturdy mechanism with the temperature dial at the top and the comfort dial at the bottom.

Comfort Dial.

The most recent development in the design of these thermostats is the addition of an adjustable so called comfort dial already mentioned above for tuning the thermostat. A range of adjustment is essential, not only because of the various conditions already mentioned, but because in cold weather setting should differ from that in warm weather. The comfort dial utilises the preheat principle by introducing into the thermostat a predetermined amount of heat. This is done by building into the thermostat case a small electric heating unit, as shown in Fig. 2, connected in series or parallel with the load.

Conventional Operation.

Assume a gravity-type hot-water system fired by an oil burner under the control of a conventional thermostat without preheat, that is set to start the burner at 70° F. and to stop it at 72° F. When the room temperature T drops to 70° F., the burner is started, the water begins to circulate, causing a temperature rise in the radiators located in the space to be heated. The room air

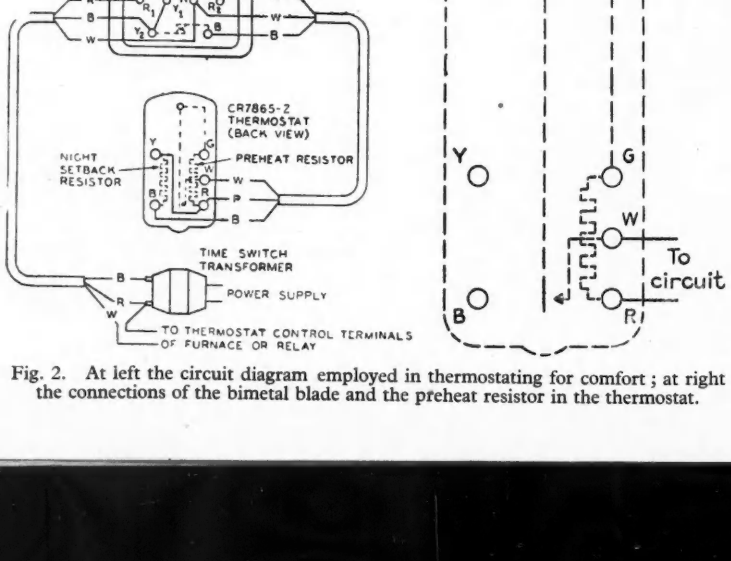


Fig. 2. At left the circuit diagram employed in thermostating for comfort; at right the connections of the bimetal blade and the preheat resistor in the thermostat.

temperature T will rise slowly. When finally the air temperature at the thermostat has been raised the necessary two degrees to cause the thermostat to stop the oil burner, heat considerably in excess of requirement has been stored in the mass of water and metal comprising the heating system. This excess heat continues to be added to the room air even though the room thermostat is satisfied, with the result that the room temperature T rises above the desired value by an amount dependent upon the storage capacity of the heating system and the heat loss of the heated space. This so-called over-shooting may be as much as six to eight degrees. As heat is slowly lost from the room, the temperature falls to the 70° F. point, at which the thermostat again initiates a heating cycle. Since T has overrun the desired value, a long "off" period results. During this time the radiator surface cools down sufficiently for the cold infiltration air to settle to the floor, hereby causing air stratification and resulting in the uncomfortable condition to the occupants known as "cold 70." Frequently this condition is experienced while the room temperature at the thermostat is still several degrees above the necessary to start another heating cycle. It is evident that this difficulty cannot be overcome by moving the thermostat to a higher setting. Homes heated with "on-off" heating systems, such as those utilising oil burners, stokers and gas burners, are more comfortable in cold weather than in relatively mild weather. The reason is, that a low outside temperature causes frequent running periods of the heating equipment, the radiators never cool sufficiently to permit air stratification. Greater sensitivity of the thermostat is only a partial solution, overshooting of temperature always exists to some extent.

Preheat Operation.

In a thermostat for preheat operation a small electric heater within the thermostat case is energised at the same time that the heat source, e.g. the oil burner is started. After a definite length of time (usually after about 12 to 15 min. in a radiation system) the temperature inside the thermostat T_t has been raised to the shut off point, and the oil burner is stopped. Due to the slow transfer of heat from the heater to the radiator and then to the room air there has probably been no appreciable rise in the temperature of the room T surrounding the thermostat case, yet the oil burner operation has been stopped and a measured amount of heat has been added to the system. Immediately upon opening the circuit to the oil burner, the preheat unit begins to cool. The temperature inside the thermostat case T_t will slowly drop due to the cooling of the preheat unit, while the temperature T will slowly rise due to absorption of heat from the radiation system. A balance between air and thermostat temperature T and T_t is ultimately reached. Because there has been little excess heat introduced into the system there will be but little over-running of the room temperature T, with the result that when heat is again lost from the room in a greater rate than the stored heat in the system can supply it, another heating run will be started. The result of this action is a number of heat calls, each of relatively short duration, and the radiators remain warm continuously. Thus, in addition to maintaining of a narrower range of temperature, the tendency toward air stratification due to cold radiators is reduced.

Fig. 3 illustrates the action of a thermostat adjusted for a difference between "on" and "off" temperatures (mechanical differential) of three degrees, a preheat resistor capable of five degrees of preheat, and a dial setting of 70° F. At a room termperature T of 70° F., the thermostat will start the heating equipment and energise the preheat resistor. The temperature inside the thermostat case T_t begins to rise along the curve ACB, and would become constant at 75°F if permitted to continue. However, when the thermostat temperature has been raised to 73° F. (the shut-off point) the heating equipment will be stopped and the preheat resistor de-energised. If T has not changed, T_t begins to fall along curve CD. Unless T drops below 70° F. this curve will not cross the horizontal axis, and as a result the heating equipment will not begin another operating cycle. Now, assume a drop of T just sufficient to cause the thermostat to close its circuit at point D. T_t begins to rise along curve DFE, stopping at F. Assume that T has meanwhile dropped to 69.5° F, T_t will fall along curve FHG and the heating equipment will be started at point H causing Tt to rise along curve HKJ. However, the preheater unit will not have completely cooled from the last cycle at point H, and consequently the effective portion of the temperature rise curve is somewhat flatter, giving a longer "on" period. When the cut-off point K is reached, the thermostat begins to cool. When T has dropped to 69° F. the cooling curve KML will be steeper and the "off" period will be shorter. In excessively cold weather this variation in length of the "on" and "off" periods will continue, until the room temperature drops below 68° F. at which point the heating equipment will operate continuously since even though the preheat has raised T_t its full five degrees, T_t will be short of the 73° F. point at which the thermostat contacts open.

The tendency of a preheat thermostat to lower the temperature at which the heating equipment is cut in, as longer "on" periods are required, is referred to as the subcalibration of the instrument. The maximum value of the subcalibration is the difference between the preheat and the mechanical differential, that is 2 degrees for the thermostat of the example discussed above. Maximum subcalibration occurs only when continuous operation of the heating equipment is necessary, a remote possibility, as most equipments are installed with capacity in excess of requirements.

The preheat design is very advantageous for the change without overshooting of a night temperature (e.g. 60° F.) to a day temperature of 70° F.

Comfort Dial Settings.

The chief advantage of the comfort dial, shown in Fig. 1, lies in its ability to admit measured quantities of heat to the space that is to be heated and to increase these quantities with demand, so to obtain the desired temperature by many short operations of the heating

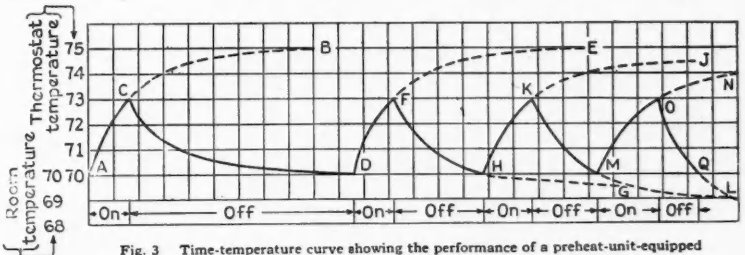


Fig. 3 Time-temperature curve showing the performance of a preheat-unit-equipped thermostat when the room temperature continues to fall below 70 F

equipment instead of a fewer long runs, which produce overshooting. The optimum measured quantity, which causes no overshooting, varies for different types of heating systems and likewise varies for different installations of the same type of equipment.

The comfort dial provides means for changing the running period by varying the mechanical differential. With a fixed excitation of the preheat element, a small differential gives a short operating period and a larger differential gives a long operating period. Previous designs of thermostats required an internal adjustment, which could not be made but by a competent service man. The comfort dial enables the home owner to "tune" the thermostat to the characteristics of the heating system and the season of the year.

Fig. 4 shows the per cent. running time for various positions of the comfort dial; 50% running time is obtained with the comfort dial in position No. 1 (extreme right position), when the room temperature drops 1.5 degrees, with the dial in position No. 3 (centre position) when the room temperature drops slightly more than a degree and with the dial in position No. 5 (extreme left position) when the room temperature drops only 0.1 degrees. From these curves it is apparent, that while position No. 1 gives a shorter operating period, the tendency towards subcalibration of the instrument is more pronounced than when position No. 5 is used, giving a minimum of subcalibration and providing long running cycles, which might result in temperature overshooting. A setting somewhere between position No. 1 and 5 will therefore be found to give the maximum heating comfort.

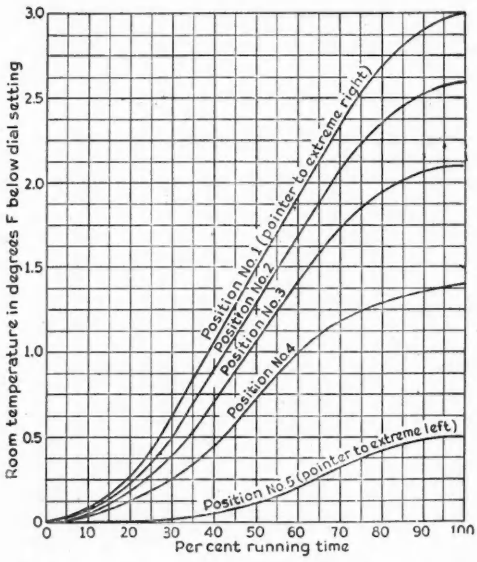


Fig. 4. Curves of per cent running time for various positions of the comfort dial.

SOME ASPECTS OF INDUSTRIAL LUBRICATION.

By W. J. HUND, R. G. LARSEN, OTTO BEECK and HAROLD G. VESPER. (From *Mechanical Engineering*, Vol. 64, No. 7, July, 1942, pp. 525-530).

ONE of the primary functions of a lubricant is to reduce the friction between moving metal parts and thereby to reduce wear of these parts. For most industrial equipment the most essential property for a lubricant to possess is sufficient viscosity to insure that hydrodynamic lubrication prevails at all times The chief insurance of good lubrication for bearings is that the design be such that the oil trapped or wedged between the moving parts cannot escape and that enough of it is trapped to separate the moving parts completely and not permit them to touch even under shock load conditions. When the surfaces or projecting asperities on the surfaces of moving parts are permitted to make contact, which generally occurs under high pressures, or low sliding velocities, then wear begins to take place.

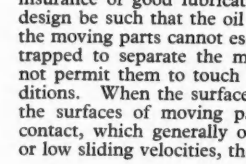
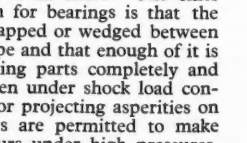


Fig. 1. Co-efficient of friction in regions of boundary and hydrodynamic lubrication.



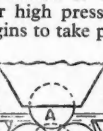


Fig. 2 (right). Four-ball bearing.

At that instant the oil film is extremely thin, and it is what happens in this film and on the contacting surface that provides the real problem of "wear." Here viscosity is not considered to be the most important property of an oil, for many engineers and operators speak of "oiliness" and "film strength" to designate mysterious properties of oils which permit them to reduce wear under these severe conditions of thin-film or boundary lubrication. However, it is unsatisfactory to ascribe such differences, if they do exist, to a vague and unknown property: rather, it is important to understand more of the mechanism of boundary lubrication and the effect of various chemical factors.

The Mechanism of Boundary Lubrication.

A characteristic of lubrication under boundary conditions is that the co-efficient of friction is practically independent of both viscosity and velocity. This is illustrated in Fig. 1, which shows the typical relation between co-efficient of friction f and ZN/P (the product of viscosity and velocity divided by pressure). The region of hydrodynamic lubrication is that to the right of the minimum, and the region of true boundary lubrication is the short horizontal portion close to the axis. Between these is a transition region, indicated by broken line, which may be called one of quasi-hydrodynamic or partial boundary lubrication. Different oils have different co-efficients of boundary friction, and those with low values are said to have more "oiliness." Certain substances having long hydrocarbon chains with polar groups on the end are effective in reducing co-efficient of friction when added to an oil such as medicinal oil, which is free of these materials. Chemi-

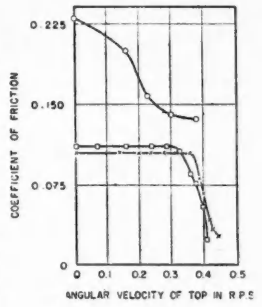


Fig. 3.
o White oil; □ white oil + 1 per cent. oleic acid; × U.S.P. oleic acid.

cally, it would seem that reduction of co-efficient of friction must be due to absorption of the long-chain polar compounds on the rubbing surfaces, although the mechanism of this action has not been understood.

The work in our laboratories on this subject was described recently by Beeck, Givens, Smith and Williams, and was performed with a machine utilizing the four-ball bearing as illustrated in Fig. 2, which is a diagram of the bearing. If the co-efficient of friction were constant, it could be calculated from the time necessary for the top to stop spinning after receiving a certain initial angular velocity. Careful analysis showed, however, that the co-efficient of friction is not constant over the whole velocity range. When the co-efficient of friction is plotted against velocity, curves of the type shown in Fig. 3 are obtained.

The curve for white oil alone is typical of the high and erratic values obtained with this material; such behaviour results from the fact that for white oil no definite state of lubrication is established under these conditions of velocity and pressure. The curves for oleic acid and for white oil plus oleic acid are characteristic of those for materials containing long-chain polar compounds. Even though the entire operation is in the region of boundary lubrication where, as explained, it has been assumed that the co-efficient of friction is constant, it will be noted that at velocities above certain critical values, which are quite reproducible, the co-efficient of friction drops off rapidly and that below these values it is constant as expected. Thus the true region of boundary lubrication is that relatively narrow region within which friction is actually independent of viscosity.

The low co-efficient of friction obtained at relatively high velocities must be caused by a state of quasi-hydrodynamic lubrication, or what may be called a " wedging effect," due to a surface of the oil and the availability of a sufficient quantity to be wedged. In agreement with this expectation, it was found that monomolecular layers of these polar materials did not exhibit this effect, but that it does occur with flood lubrication using these polar substances. Also it was shown that viscosity had little effect, hence this behaviour does not appear to be associated with the properties of the lubricant in bulk.

Using the electron diffraction camera, it was found in fact that all substances showing the wedging effect have a highly oriented surface structure. The lowest critical velocities at which the effect first appears are obtained with the most highly oriented films, the hydrocarbon chains extending out either perpendicular or at an angle. These oriented materials may even be hydrocarbons themselves, although such films are less stable under heat. These results were confirmed by the fact that at higher temperatures in the four-ball test, only the temperature stable polar films have low critical velocities. It was found also that above the critical velocity the electrical resistance between the balls is very high, 10,000 ohms or more, but that below the critical velocity it drops to 250 ohms or less. This indicates that the observed critical velocity is a point at which physical separation of the bearing surfaces is markedly increased. This is in line with the concept of lubricant wedging. It should be mentioned that a considerable degree of polish must be maintained for the wedging effect to occur.

Wear Prevention: Role of Chemical Polishing Agents.

It is an observed fact that reduction of the co-efficient of boundary friction does not necessarily cause a reduction in wear. The reason for this is obvious, when it is considered that wear takes place at isolated spots, which are small compared with the whole surface, and that a momentarily high co-efficient of friction at this point does not affect the over-all friction.

Bowden has shown that the most carefully machined parts have a microscopic roughness and that the applied load is not uniformly distributed over the complete surface, but is carried by a few high spots, perhaps 1/10,000 of the apparent area. At these high spots under boundary lubrication conditions, the enormous pressures produce excessively high temperatures resulting in welding and tear and a general roughening of the surfaces leading to higher and higher temperatures of the bulk of the metal and ultimate seizure and breakdown. All of the oil, save the tightly held monomolecular layer would be squeezed out, and absorbed layers of polar molecules could not possibly give protection since such films would be destroyed instantly because of the high temperatures and pressures. It is clear that if the load were evenly distributed over the entire area, then much less severe conditions would prevail. Accordingly if the surfaces were highly polished and could remain so, then the opportunity for polar agents to be effective is much greater.

In studying this possibility, the extent of wear with the four-ball machine was measured in three ways. First was to measure the diameter of the scar worn into the lower ball, Fig. 4. The second method was by colorimetric determination of the iron content of the oil held in the cup. The third was by measuring the time to wear through a plating of copper or other metal on the steel balls.

Using these methods we have found a large group of chemicals, related to phosphorus, which are capable of giving very low wear by producing and maintaining the rubbing surfaces in a polished condition. The best known example of this group of substances is tricersyl phosphate, with which most experiments were performed.

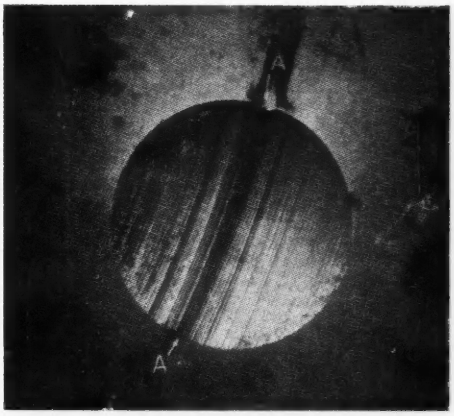
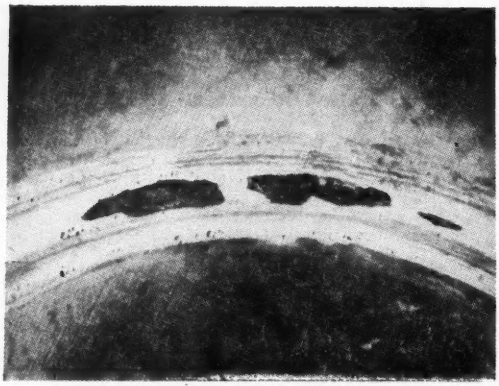


Fig. 4. Wear scar obtained on four-ball tester.



(White oil + 1.5 per cent tricresyl phosphate).

(White oil).

Fig. 5. Wear tracks on gold-plated ball after 97 minutes running at 120 r.p.m. and 2.2 kg load.

It was shown that this material acts by a corrosive rather than a protective action. Thus the high spots, which are hot, react very rapidly with the wear reducing agent to form a metal phosphide. The metal phosphide alloys with the surface and lowers its melting point very considerably, thus permitting the metal to flow into the valleys, resulting in a highly polished surface. The chemical action is temperature-selective so that when there are no high pressures and temperatures there is no chemical action.

To check these ideas, a large number of substances were tried, such as arsenic and antimony compounds, which are also capable of alloying with iron; all were found to be more or less effective. To test the theory in another way a phosphorus compound was used with a tin surface. Now phosphorus alloys with tin to raise the melting point, and accordingly the smoothing action should not take place. The results were as expected—the phosphorus compound was found to actually increase the wear on a tin surface by a factor of four. On the other hand phosphorus gives a low-melting alloy with copper, and accordingly the phosphorus compound should reduce wear on a copper surface. This was found to be the case. Also, a metal, such as gold, which does not alloy at all with phosphorus should show the same rate of wear whether or not a phosphorus compound is present. This also proved to be the case, as shown in Fig. 5.

It was earlier stated that polar compounds are useful only when the surfaces are maintained in a polished condition. This led to experiments to see the effect of combining a chemical polishing agent with a polar wedging compound. The data in Table I. show that the combinations are about twenty times as effective as the polar material alone and about twice as effective as the polishing agent alone.

TABLE I. Wear of Copper-plated Balls.

MATERIAL ADDED			Wear-reduction factor
Polishing Agent		Wedging Compound	
Tricresyl phosphate (1.5%)		.. ..	5.4
Tricresyl phosphate (1.5%)	+	oleic acid (1.0%)	10.3
		Oleic acid (1.0%)	1.4
Tricresyl phosphate (1.5%)	+	copper oleate (1.0%)	10.3
		Copper oleate (1.0%)	1.1
Tricresyl phosphate (1.5%)	+	stearone (saturated solution) ..	8.6
		Stearone (saturated solution) ..	1.4
Tricresyl phosphate (1.5%)	+	mesityl heptadecyl ketone (1.0%)	10.4
Tricresyl phosphate (1.5%)	+	tristearine (1.0%)	14.2
Triphenyl arsine (1.5%)		.. ..	12.2
Triphenyl arsine (1.5%)	+	oleic acid (1.0%)	2.4
Triphenyl arsine (1.5%)	+	mesityl heptadecyl ketone (1.0%)	17.6

Extreme-Pressure Agents.

It is now possible to compare the action of chemical polishing agents just discussed with that of agents used in extreme-pressure oils. In all cases, equal distribution of the load over the bearing area is essential; thus a high polish is essential. Both E.P. agents and chemical polishing agents will do this, and both do it by chemical attack due to high temperature. Even with the load evenly distributed the minimum load in these bearings may still be too high for maintenance of a stable oil film, and metal to metal contact may occur. Since the area of contact is large, seizure under these conditions is catastrophic compared to the seizure at minute points experienced under normal wearing conditions. The distinction between these two types of agent is that the surface left by the chemical polishing agent is apparently in condition to weld with the opposite member, while on the other hand the polishing action of the E.P. agent leaves a surface film such as a sulphide or chloride which does not permit the metals to weld together. It is interesting to note that if the surfaces are polished mechanically, the maximum load which a mineral oil can stand (film strength) is practically as high as with the oil containing the E.P. agent. In the case of mineral oil, the polished surface is soon lost, however, and failure occurs.

Bearing Finish.

On highly loaded parts equal load distribution is essential, but it is also necessary that the surface contain oil channels or reservoirs to help support the load as well as to supply oil to replace that squeezed out because of the high pressure. The essential thought here, as shown in Fig. 6, is that these channels should be below a plateau and not be formed between protuberances. With this plateau there is no chance for interlocking of contacting surfaces which would result in tearing, and the load may still be distributed over what may be called the major apparent bearing area.

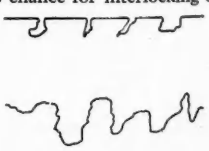


Fig. 6 Types of surfaces.

Effect of Pressure on Viscosity.

From the standpoint of lubrication the change of viscosity with pressure is more important than the change with temperature, particularly when the oil is used in machinery operating at a pressure of several thousand pounds per square inch. Under such conditions, unless viscosity is sufficiently high, the thickness of the lubricant film is reduced to the point where pro-

jecting asperities may easily penetrate. As shown by Everett and more recently discussed by Givens, the increase in viscosity with pressure, however, is considerable; thus, at 20,000 lbs./sq. in., the viscosity may be as much as 200 times as great as at atmospheric pressure. It so happens that oils which decrease more rapidly in viscosity with increase of temperature also increase more rapidly in viscosity with increase of pressure. In fact, a rough calculation shows that in general an increase of pressure of 200 lbs./sq. in. has about the same effect on viscosity as lowering the temperature by 1 F.

Turbine Oils.

The subjects so far mentioned are all problems in non-hydrodynamic lubrication. Some problems arise, however, even where hydrodynamic lubrication can be provided. An example is the lubrication of turbines, where rust, emulsions and sludges may form.

Early types of turbine oils deposited sludge, which not only interfered with oil flow but also stabilized emulsions with the ever-present water, and these were sometimes so serious as to render separation of the water impossible. In the initial attack of the oil industry on the problem, refining processes were evolved to reduce sludging, but it was soon found that soluble deterioration products, including acids, were equally harmful. This led to a concentration of attention upon oxidation stability to the exclusion of other considerations, such as the ability of an oil to wet metal surfaces, and thus to prevent rusting.

Troublesome rusting in turbines was first experienced about two years ago in the governor mechanism, and more recently even the rusting of gear has occurred. These weaknesses were early recognized and considerable work has been done to produce stable but non-rusting oils. First it was necessary to develop tests for stability of the oil toward ageing and for rusting tendencies. In developing the stability test the effect of catalysts, water, temperature, volatile oxidation products, and the like, all had to be evaluated. In the test as developed, both iron and copper are present as catalysts, together with water, temperature is held at 100° C., and volatile oxidation products are retained as much as possible by refluxing. The test correlates well with practice, inasmuch as oils are rated in the same relative order as by their known service records.

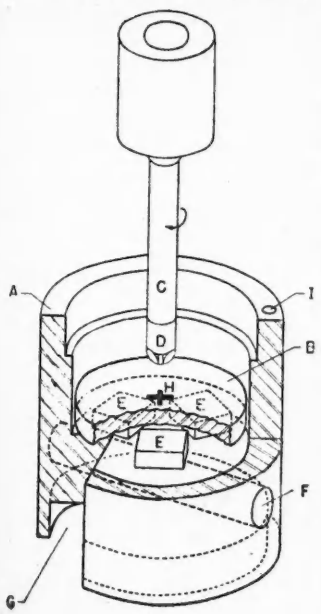


Fig. 7

Thrust-Bearing Corrosion Machine, general construction (a) steel cup; (b) hardened steel disk; (c) driving spindle shank; (d) fiber tip; (e) bearing specimen and support; (f) hole for thermo-switch; (g) recess for electric heater; (h) recess to accommodate tip D; (i) thermometer well.

Bearing Corrosion.

Another interesting problem in the field of hydrodynamic lubrication, though of more importance in the lubrication of internal-combustion engines than for other types of machinery, is the corrosion of hard bearing alloys, such as copper, lead, cadmium silver, and cadmium nickel. These are used in high output engines under conditions of temperature and load which are more severe than babbitt will withstand.

When this difficulty arose, very little was known as to its cause, nor were there any reasonably effective means of combating it. The first investigations were carried out in actual engines, whose anatomy is so complex that the results of the experiments could not be interpreted with certainty and simplicity. On the other hand, laboratory experiments that were devised to simplify the studies did not successfully imitate the high rate of shear in the oil layers next to the bearing surface, which appears to be an essential condition of the corrosion in actual engines. Fig. 7 shows a sectional view of the machine developed in our laboratories and recently described by Talley, Larsen, and Webb for study of the various factors that control the appearance and extent of bearing corrosion. To ensure hydrodynamic conditions it employs a Kingsbury

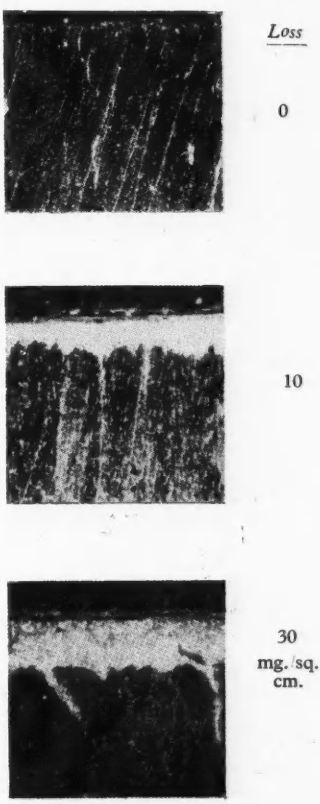


Fig. 8.

thrust bearing. The test conditions are ordinarily set so that the corrosiveness of an oil is measured as independently as possible of all other factors. It is also possible to alter the test procedure to provide a considerable degree of oxidation during the test if this is desired.

The photomicrographs shown in Fig. 8 are cross sections of copper-lead bearing specimens after test in the machine. Different degrees of corrosion penetration are indicated.

Studies with the machine have shown that temperature is a very important factor in the corrosiveness of an oil; and if the temperature at which the corrosiveness in the test becomes pronounced is lower than the operating temperature of the bearing in service, corrosion difficulties may be expected.

A SURVEY of the PRESENT-DAY IMPORTANCE OF EXTINGUISHING COILS (Arc Suppression Coils) as a PROTECTION AGAINST EARTH FAULTS.

By A. v. GASTEL. (From *Brown Boveri Review*, Vol. 26, No. 6, pp. 143–47, June, 1941.)

Extinguishing coils were introduced 25 years ago with the purpose of compensating the current flowing to earth, when an earth fault occurs in overhead networks of low and medium voltage. Thanks to the excellent results recorded in practice everywhere the coils soon found an application even on networks of the high voltage range and the inductive earthing of the neutral point of cable networks has also become common practice. Some experience gained up to recent years are discussed in the following paragraphs.

I. Rating of the Extinguishing Coils.

The output of the coils is determined by the magnitude of the earth fault current and the voltage of the network. As the earth fault current increases proportionally to the network voltage the output of the coils is a quadratic function of the voltage. Therefore very big outputs were reached for extra voltage transmission systems, which had to be split up between several coils. The biggest coil rating is limited by the loading gauge of the railway, assuming conveyance to site of the coil fully mounted. In many cases the rating of the coil is limited by the output of the transformers on site. Finally, in the case of very extensive high-voltage transmission systems concentration of the extinguishing coils in one place may produce big rises in voltage on the remotest points of the transmission system. Biggest output of coils built by Brown Boveri are :

for 220 kV transmission overhead lines	27,240 kVA
for 150 kV overhead lines	12,000 „
for 150 kV cable plants	18,000 „
for 120 kV overhead lines	10,000 „

Fig. 1 shows a 23,300 kVA extinguishing coil for a 210 kV network.

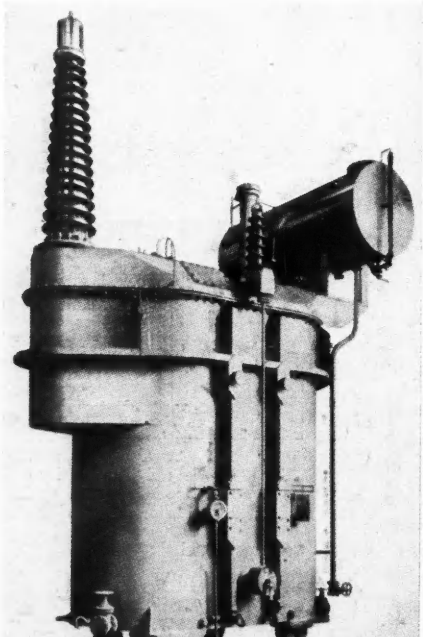


Fig. 1. 23,300 kVA extinguishing coil for a 210 kV network. Design with tap-changing switch and with secondary winding for 4,000 kW.

II. The Rating of the Extinguishing Coil.

The great majority of coils are designed for a 2-hours rating, as in most cases this time is sufficient to carry out the necessary change-over operations on the system, when a permanent earth fault occurs. The heat capacity of the coils is big enough to allow of a 2-hours rating without introducing any special cooling measures. (See Fig. 1.) Coils for longer operation carry the designation : 24-hours rating. The cooling surface of such coils is increased by the addition of radiators. But the active part is the same as for coils for 2-hours rating.

III. The Tuning of the Extinguishing Coil.

Apart from the adjustment to resonance conditions (earth-fault current equal to inductive current produced by star voltage), that to dissonance conditions has also been found useful, when the capacity to earth of the three phases differs. Such adjustment limits the displacement of the voltage of the network against earth. Another solution of the problem to limit the displacement of the neutral point in asymmetrical networks consists in increasing the watt component of the earth-fault current. Such a higher watt component is produced by the load of a secondary winding, which is connected up under ordinary conditions, but cut out immediately, when an earth-fault occurs. The coil is adjusted for resonance, so that the advantages of resonance and dissonance tuning are combined.

The increase in the watt component of the earth-fault current can be utilised to cut out permanent earth-faults selectively. The resistance is cut out only momentarily, so that the earth-fault

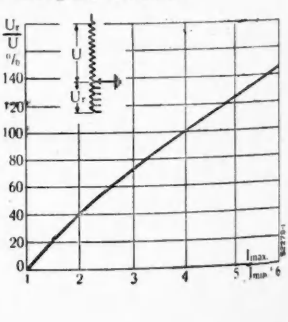


Fig. 2. Regulating range of extinguishing coils as a function of the current range.

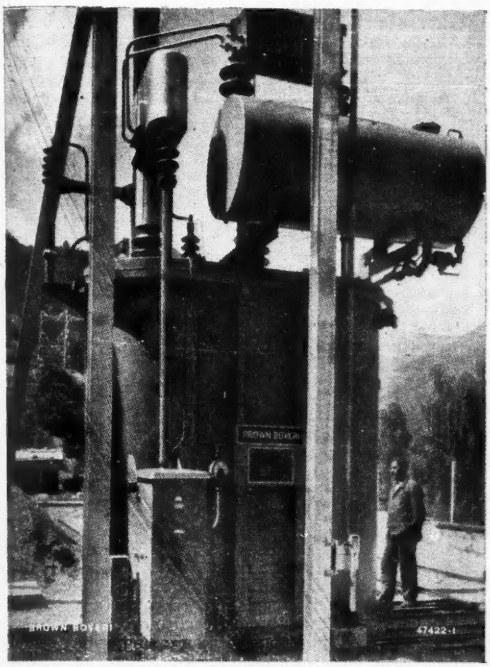


Fig. 3. 12,000 kVA extinguishing coil for a 150 kV network. The design with on-load tap-changing switch with spring drive allows of adjustment being made without preliminary cutting out of the coil from the network.

arc extinguishes. After the resistance has been connected again, the earth-fault relays, which operate with a short time lag, have as duty to determine which is the defective line section and cut it out from the network.

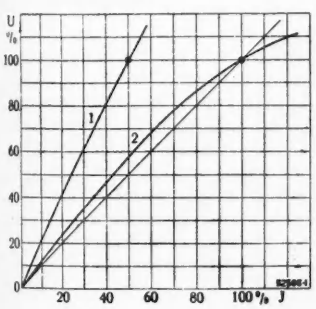


Fig. 4. Current curves of an extinguishing coil for different number of turns connected.
1. With all the turns connected (J minimum).
2. With the minimum of turns connected (J maximum).

The curve 2 deviates from the straight line because the induction is greater (saturation).

IV. The Regulation of the Extinguishing Coil.

The development of on-load tap-changing switches for regulating transformers has influenced also the tap-changing switches of the earthing coils, suitable formerly only for tap-changing, when the coil was not connected to its transformer or the transformer was cut out. The steps of extinguishing coils are bigger and cover a wider range of regulation than those of transformers of usual design. Fig. 2 shows that in order to attain a regulation of the coil current in the ratio of 1 to 4, which may be considered as normal, the regulation range has to be 100 % of the voltage across the coil (phase voltage of the network).

Fig. 3 shows an extinguishing coil with on-load regulation of 12,000 kVA to protect a 150 kV line. The tap-changing switch is seen in the foreground. It is worked through a spring (power storage) drive or by manual or push-button control.

The coil with a fixed air gap and taps on the winding works with a variable induction. According to whether the iron core is more or less saturated, the current curve varies. The curve 1 (Fig. 4) is valid for operation with the full number of turns and with a minimum of induction. The curve 2 is valid for operation with the smallest number of turns and the highest induction and shows clearly the effect of saturation. The proportionality between voltage and current is lost under voltage fluctuations. This necessitates under certain circumstances a correction of the adjustment according to the network voltage, which can only be carried out easily on a coil with on-load regulation by tap-changing switch.

Measurement of the neutral point voltage by a secondary winding on the core of the coil is complicated with coils tuned by tap-changing. These complications are eliminated in the new design because it works to a constant number of turns and, therefore, with constant induction.

V. The Extinguishing Coil with Continuous (Smooth) Regulation.

The extinguishing coil, which can be regulated continuously has a winding without taps, but has an air gap, which can be regulated. Therefore there is no difficulty in placing a secondary winding for constant

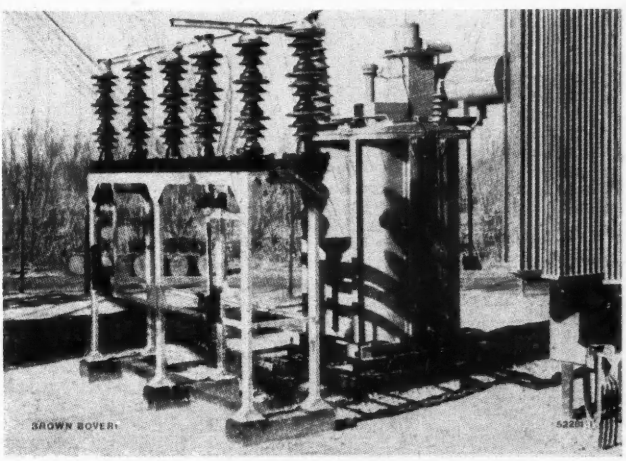


Fig. 5. 5,500 kVA extinguishing coil with continuous regulation to protect a 100 kV network. This design allows of very precise adjustment during service without cutting out the extinguishing coil from the network.

voltage on its core, either voltage measuring or power producing windings. This new design of coils has the great advantage of a very simple arrangement of the winding, which contains no points of reflection for incoming voltage surges as formed by the taps of the coils of older design.

The regulation can be carried out under load and the adjustment can be made very exactly in accordance with the earth current of the network, which varies with the value of its voltage and the condition of the surface of the ground. The automatic regulation of such coils will bring a perfect solution of the problem.

Fig. 5 shows a coil with continuous regulation in a 100 kV plant.

THE AUTOMATIC REGULATION OF EARTH FAULT EXTINGUISHING COILS.

By DR. P. WALDVOGEL. (From *Brown Boveri Review*, Vol. 26, No. 6, pp. 147–49, June, 1941.)

AFTER having attained a high degree of perfection in the design of the extinguishing coils there was still one weakness to overcome, namely to know by what measures the extinguishing coil is to be regulated so that a suitable tuning between the inductance of the coil and the momentary capacity of the system is reached in every case occurring in service. Means have been evolved to equip the coils for full automatic regulation. The regulating devices necessary for this only operate as long as the network is perfectly insulated, but they are interlocked as soon as an earth-fault develops on one of the phases. The coil being constantly tuned to the momentary capacity of the network, it is unnecessary to continue regulation, when it is actually in operation.

The fundamental diagram of connections for automatic control of the tuning of an extinguishing coil on a sound network is shown in Fig. 1. All the parts defined in thin lines belong to the automatic regulating device. This device proper is designed as a Ferraris rotating system with two windings 6 and 7. The voltage winding 6 is connected to an auxiliary transfer 5, the voltage of which E is in principle in phase coincidence with that of the network to be protected. The current of the extinguishing coil J passes through the current winding 7 through the intermediary of a current transformer not visible in the illustration. The Ferraris device measures the product $E\,J \sin \varphi$ (φ being the phase angle between E and the current J). The regulating device has two contacts, which adjust the extinguishing coil under voltage.

The current J, which flows in the circuit of the coil and the capacitance of the line to earth, is in phase with the voltage E, if the circuit is in a state of resonance ($E\,J \sin \varphi = O$). The current lags on voltage E, if the network is undercompensated and leads on it, when it is overcompensated. This will make clear, why the regulating device always tunes the network to a state of resonance.

There is no difficulty in tuning the network to a state of dissonance, e.g. by imparting to the regulator an additional voltage so that it maintains the product $E\,J \sin \varphi$ at a constant value which differs from zero. From this explanation it follows that it suffices that the auxiliary network should have a frequency, which is not absolutely the same as that of the network to be protected.

When the network is not symmetrical, that is when C_1, C_2 and C_3 have not the same value, an asymmetry voltage E′ of the neutral point results, which produces a current J′ in the circuit formed of the coil inductance L and the sum of the capacities $C_1 + C_2 + C_3$ and this current is added to the current J already mentioned above. The torque on the regulator corresponds to the sum $E\,J \sin \varphi + E\,J' \sin \varphi'$ where φ' is the angle formed by the current J′ and the voltage E. In order to avoid an influence of the current J′ on the regulator the voltage E is modulated, that is to say its magnitude is constantly varied while maintaining its phase position unchanged. A simple kind of modulation transformer is formed by a single phase induction regulation, the rotor of which is constantly and slowly revolved, producing for example 4 cycles for a 50 cycle network. This has no effect on the sign of $E\,J \sin \varphi$, whereas $E\,J' \sin \varphi'$ fluctuates with the frequency of modulation around zero as medium position. If the inertia of the regulating device suffices, it will not react to the torques produced by $E\,J' \sin \varphi'$, but only to those of $E\,J \sin \varphi$. Thus the proper working process of the regulating device is made independent of the magnitude of the asymmetry voltage of the network.

If the network is protected by several extinguishing coils with automatic regulation, they can be arranged so that they never act against each other.

Tests were carried out with an extinguishing coil of 12,000 kVA 150 kV equipped for automatic on-load tap switch giving about 4 % per tap. When a part of the network of 8 km, about 5 % of the network was connected up or cut out, the regulating device responded by displacing the tap by one step.

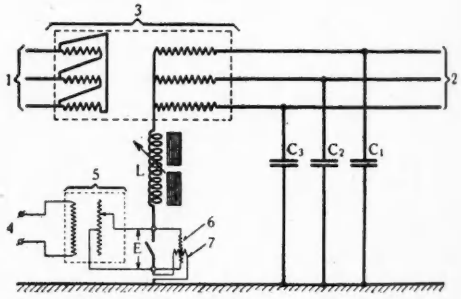


Fig. 1. Fundamental diagram of connection for the automatic control of an extinguishing coil on a sound network.

1. Primary network
2. Secondary network
3. Transformer
4. Auxiliary network
5. Modulation transformer
6. Voltage coil of the regulator
7. Current coil of the regulator

L. Inductance of the extinguishing coil

C_1, C_2, C_3. Capacities against earth of the three conductors forming the line.

EXPLOSIVE RIVETS FOR METAL-CLAD CONTROL SURFACES

By OTTO BUTTER, Rostock. (From *Luftwissen*, Vol. 9, No. 6, June, 1942, pp. 181-182).

STRUCTURAL members of the closed section type common in aircraft design were the source of great difficulties when metal construction was introduced. Such members were, therefore, never made fully metal-clad. These members include control surfaces, notwithstanding flaps and tabs. The lack of a suitable connecting element has lead to a mixed construction, whereby part of the structure was covered by metal skin plating, and for the rest of it fabric was employed. The nose of the section up to the spar was made of metal, and thus formed a torsion tube, the rear part, consisting of ribs, was fabric covered. Many factories still use this method, although for military reasons a fully metal covered surface appears to be highly desirable. Apart from this, another reason for the desirability of fully metal-clad surfaces is their increased torsional strength.

This cannot be achieved, however, with normal riveting of smaller and medium control surfaces. Openings and cut-outs must be provided to obtain access for riveting, and thus the production becomes both complicated and uneconomical. In order to obviate this, hollow tubular rivets have been used in the past, but the strength of these is rather low, and moisture can enter through the hollow shaft the inner structure and watertightness is a matter of impossibility.

Only explosive rivets enable the designer to make fully metal-clad control surfaces which lend themselves to a practical way of production. Whereby the whole structural member is riveted as far as possible with ordinary rivets, the last strip of sheet being fastened then by means of explosive rivets. In this way completely watertight control surfaces can be made, and the joints are clean and neat.

The following descriptions of some constructions proved, in the workshops of the Heinkel Aircraft factory, to be the most satisfactory.

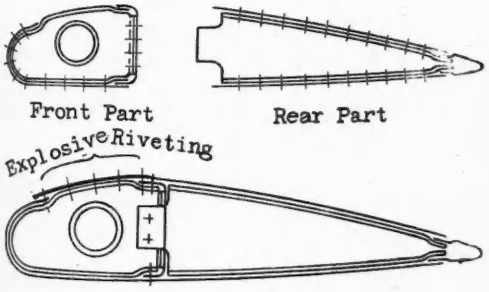
Fig. 1 shows a landing flap built in two separate parts and on two separate jigs. The rear part can easily be riveted as one side is open. It consists of ribs, an end profile and skin plating, the free end of which is long enough to overlap the spar. The front part consists of the spar, nose ribs and part of the skin plating.

In a third jig these two parts are joined ; the front and rear ribs riveted together, the overlapping skin of the rear part riveted to the spar. The uncovered part of the nose must be large enough to allow easy access for riveting of the two parts together. As a last operation, the uncovered part of the nose is closed by a strip of sheet, fastened by explosive rivets (Fig. 2).

To facilitate the riveting with explosive rivets, care must be taken to ensure in the design stage that two sheets only be joined in this way. Where the ribs are joined to the spar the number of sheets will be unavoidably three. Careful clamping on jigs will here be necessary before riveting. The same applies to those parts at the front of the closing strip where it has to be joined to the nose rib and the skin plating of the nose. In order to secure tight attachment of the sheets only slight pressure should be applied on the heating iron on these places as the covering strip is of thinner gauge than the spar or ribs.

Fig. 3 shows an elevator where the evenly distributed balancing mass is right at the nose. For this reason the strip fastened by explosive rivets is also at the nose. This type of construction is advantageous for mass-balanced control surfaces, as the mass at the nose acts with the greatest possible leverage. For greater stiffness the covering sheet is thick and contributes thus to the mass-balance.

The rivet heads for greater sheet-thickness can be countersunk, with thinner gauges preferably mushroom heads.



Figs. 1 and 2

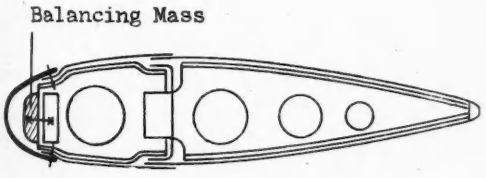


Fig. 3

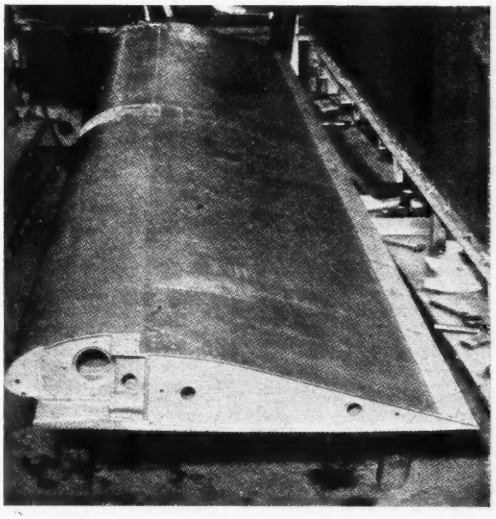


Fig. 4

To check the exploded rivets—as must be done in case of torsion tubes—openings in the nose ribs must be provided, which allow the introduction of optical apparatus for internal testing.

Fig. 4 shows a landing flap manufactured according to the principles illustrated in Figs. 1 and 2. The advantages of the method are obvious. Explosive rivets can be used to a still greater extent in repair work on partly, or fully metal-clad control surfaces.

PROBLEMS OF NAVAL AIRCRAFT.

By Prof. Dr. Ing. H. Ebner, Hamburg. (From *Luftwissen*, Vol. 9, No. 5, May, 1942, pp. 142-154).

Land Aircraft or Naval Aircraft ?

Naval aircraft must be airworthy and seaworthy. Owing to this double task the naval aircraft is inferior to land aircraft in flight, at least as far as present sizes of aircraft are concerned.

One might assume that the flying boat compares favourably with the float seaplane, its hull serving as buoyant body and fuselage at the same time ; this, however, is not the case since in smaller flying boats, to avoid damage by contact with water, a number of parts, e.g., engines, must be positioned higher from the water line than would be otherwise necessary. To keep the tail surface clear of the wash during take-off the after-body must be raised, resulting in an aerodynamically unfavourable shape. In addition, to ensure the lateral stability, wing tip floats, or at least stubs, are required which increase the weight and also the drag, as on small flying boats these cannot be made retractable. Only the largest types of hulls can be designed stable enough to eliminate all stabilizing aids.

A further drawback of naval aircraft compared with land aircraft lies in the steps and chines ; the sharp edges cannot be rounded off because then the water rising up the side of the float or hull would make take-off impossible.

As to the weight of floating gear and landing gear for naval and land aircraft respectively, it can be said that up to a certain limit the former is heavier. With increasing size, the drawbacks of increased drag and weight of naval aircraft gradually diminish.

According to some U.S.A. data, flying boats of 30 tons and over are lighter than land aircraft of the same capacity. Sikorsky states that a 100 ton flying boat is 5% lighter than a corresponding land aircraft.

But even in that weight class where the flight performance of the naval aircraft is less satisfactory, there are a number of special tasks for which the land aircraft is unsuited. In the first place geographical considerations are important, such as the many lakes in Canada or Finland, or on transoceanic routes where a forced landing does not mean loss of life and machine when naval aircraft is employed. In military aviation the naval aircraft has its special duties too. The strategical advantage of " bombproof " basis should also be mentioned, as there are no runways which could be destroyed by enemy action.

Float Seaplane or Flying Boat ?

The choice between float seaplane and flying boat is governed by the purpose of employment and size.

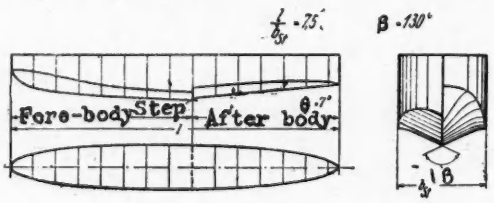


Fig. 1

In case of passenger transport or that of bulky goods, generally the flying boat presents a satisfactory solution. For bomb and torpedo carrying purposes, or for an unrestricted view downwards, the two-float seaplane is the answer. Where manœuvrability and lateral stability is required in wind and on rough sea, the two-float seaplane is generally preferred. However, for a certain weight the hull of the flying boat provides greater strength than two separate floats.

Both the flying boat and the float seaplane have their decisive spheres of applicability, and hence research problems peculiar to both categories must be dealt with.

Research Problems of Naval Aircrafts.

The Float Bottom.

The shape of the hull or float bottom must be such as to keep water resistance during take-off as low as possible. The shape of a float, modelled after a ship-hull, would result in low water resistance at moderate speeds, but at higher speeds the resistance becomes prohibitive. To avoid an increase in resistance with increasing speed, the water must be forced out of contact with the planing body. To this end steps and chines are necessary. Apart from this, the bottom of the after-body must be tapered by tilting the float about the edge of the step. For this reason all present day's hulls and floats contain features such as steps and chines and tapering of the after body bottom. In order to unify float shapes, the DVL standard float has been adopted (Fig. 1). Based on systematic tank tests and making use of the standard float, Sottorf has compiled data for the design engineer. (See *Luftfahrtforschung*, Vol. 14, 1937, No. 4/5). The relative height of the step, its position and the taper of the after body bottom (θ) are equal for each group of standard floats. Variation of the length breadth ratio $\left(\frac{l}{b_{st}}\right)$, and of the angle of V-bottom (β), is left to the designer, and so is the shape of float above the bottom. The step in the plan view, shown in Fig. 1 as a dotted line, is the projection of the plane of the step. This has been found more efficient than tapering the step towards the stern, as is customary in U.S.A. The

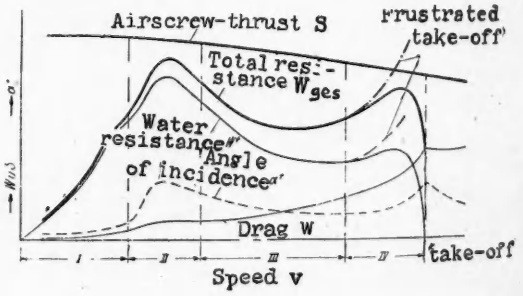


Fig. 2

V-bottom is unfavourable with regard to water resistance, and in the past flat bottoms were not unusual. For high speed take-off and landing flat bottoms would be subject to excessively high shocks, and therefore, the V-bottom is indispensable. The angle (β) is constant for the after-body. In the fore-body it is more acute towards the bow.

The Take-off.

To ascertain whether a required performance can be expected for a given engine and airscrew, the resistance at take-off must be known. In Fig. 2 the total resistance composed of water resistance and air drag is plotted against the speed. A typical case is illustrated showing the angle of incidence and airscrew thrust. Take-off is possible if the total resistance is less than the available airscrew-thrust. The difference between airscrew-thrust and total resistance represents the accelerating force, from which the time and distance required for take-off can be calculated. The accelerating force must not become zero, and if the two curves intersect take-off is not possible. This is shown in Fig. 2. The take-off can be divided into four parts. In Part 1 the float or hull behaves like a ship, to be exact, like a badly designed ship. The lift is preponderantly of hydrostatic nature. In the last third of Part 1 the flow starts to break away from the step and a cavity develops behind it. A great part of the after-body is still in contact with the water and contributes largely to the buoyancy. Its bottom receives a forward component of the normal force since the angle (Θ) is greater in this region than the angle of incidence of the fore-body. This component being greater than the frictional resistance of the after-body bottom, there is a propelling force available. The angle of trim is small in this region.

In region II. the float emerges from the water whereby the angle of incidence increases. The resistance reaches its maximum value and the speed corresponding to this condition is known as hump speed. Next only a part of the after-body remains in contact with the water, and the resistance decreases due to increase in wing lift. The resultant force on the float is now shifted forward inducing a large trimming angle.

In Part III., part of the bottom in front of the step contacts the water. The way in which the angle of incidence and the water resistance decreases is clear from Fig. 2. With increasing speed and gradually rising float from the water, the resultant resistance is displaced towards the back and the trimming angle reduced.

In Part IV., due to the V-bottom the wetted area is decreased below the breadth of the step and water is spraying backward on to the stern. As the angle of trim must increase when unsticking, a greater area of the stern becomes wetted, and the increased resistance may prevent take-off.

Scale Model Testing.

At the present it is not possible to predict take-off. Exception to this is Part III., where, based on Wagner's theory ("Ueber das Gleiten von Wasserflugzeugen," Jahrbuch 1933 der Schiffbautechnischen Gesellschaft), and the theory of plate friction (L. Prandtl, Abriss der Stroemungslehre, Vieweg & Sohn, Braunschweig, 1915), some prediction can be made. One has to resort, therefore, to scale model testing. For large flying boats, flying models have been made, but the loss of time and expense are considerable. The only economic way is model testing in water tanks, whereby the model of wood or plexiglass is towed along the tank by means of

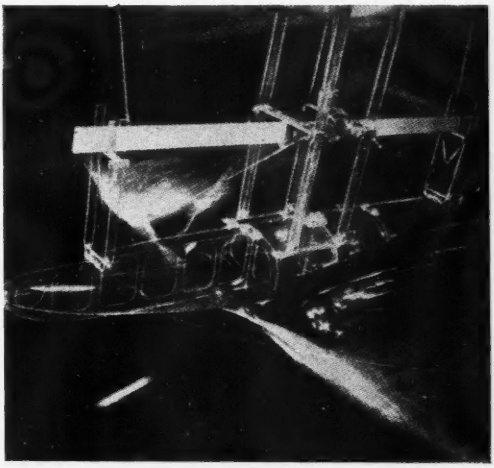


Fig. 3

a towing equipment. (See plexi-glass float in tank testing, Fig. 3). These tests can be made independently of the proposed aircraft design provided that standard floats are employed. The tank tests are then applicable to full scale aircraft in the same way as are wind-tunnel tests.

In scale model tests it is not feasible to reproduce conditions of acceleration, and tests are conducted at constant speed over a certain speed range. The error introduced by neglecting acceleration is expected to be small. Usually, the model is towed with free immersion and fixed angle of trim. Resistance and trimming moments are frequently measured, and also the draft and wetted area. To measure the angle of trim for a given trimming moment would be rather difficult, and is, therefore, restricted to investigations of the dynamical behaviour of the model when gliding on the water surface.

The test results are represented by dimensionless values and a diagram is given in Fig. 4. The dimensionless values are :

$$\text{Froude Number } Fr = \frac{v}{\sqrt{g\ b_{st}}}$$

$$\text{Loading Coefficient } C_a^* = \frac{A}{\gamma\ b^3_{st}}$$

$$\text{Moment Coefficient } Cm^*_{st} = \frac{M^*}{\gamma\ b^4_{st}}$$

$$\text{Ratio of } \frac{\text{Resistance}}{\text{Loading}} = E\,\frac{W^*}{A^*}$$

The notation is the same as before and in addition :

v = speed
g = gravitational acceleration
γ = specific weight
M^* = trimming moment
W^* = water resistance
A^* = loading of floats or hull

Asterisk denote hydrodynamical quantities. In Fig. 4 Cm_{st} and E are plotted against Fr, for various values of the angle to trim α^*. The diagram is made for a constant value of C_a^*. Similar curves can be obtained for other loading coefficients, between zero

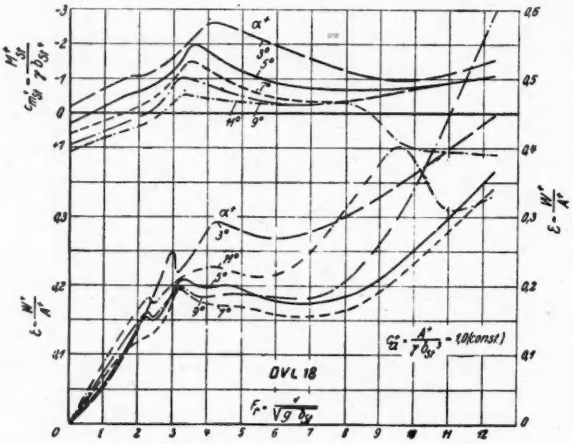


Fig. 4

and the maximum loading (Ca*max ≈ 3). For higher Froude numbers the state of flow at constant Ca* is identical to the square of the Froude number. This relation corresponds to the Newton number $\frac{A^*}{\gamma/g v^2 b_{st}2}$ and can be utilized in reducing the number of tests. As Fig. 4 shows, the lowest value of E occurs when the angle of trim is dependent on the Froude number. The design must be such that this optimum angle can be maintained without difficulty. The values of the moments at the optimum angle can be read off the top curves in Fig. 4. and must be balanced by weight, lift thrust, &c.

The designer should aim at an optimum angle of trim equal to the free taxying angle. However, this cannot be achieved in all four regions of the take-off.

The choice of the angle between wing chord and keel tangent is also of importance. If this angle is large, the water resistance is low and the drag increases. For small angles the reverse is the case. Thus there is an optimum angle for which the total resistance is a minimum. This optimum angle, however, is not constant for all take-off regions, and a very detailed aerodynamic investigation is necessary to ascertain this angle, the effect of the rudder on the angle of trim and the influence of the proximity of water upon the slipstream.

Scale effect.

The above consideration were based on the assumption that the interpretation of the model test is in accordance with Froude's law, so that if λ is the scale, the forces acting on the full scale aircraft are λ^3 times those observed on the scale. Frictional forces were neglected hereby which do not obey Froude's law but Reynold's law. This introduces a scale effect which can be taken into account by a new method developed by W. Sottorf (*Luftfahrtsforschung*, Vol. 16, 1939, No. 8). Fig. 5 shows a diagram in which the resistance was calculated from a model of $\lambda = 5.5$ for the full scale 10-ton seaplane ($b_{st} = 1.65$ m, $\Theta = 150°$).

The upper curve in the top of the figure represents the water resistance (W_h) of the model multiplied by λ, and therefore, the curve is the uncorrected water resistance of the full scale plane. It is plotted against the speed (W_h) of the actual plane, which is the speed of the model multiplied by $\sqrt{\lambda}$. The bottom graph in Fig. 5 shows the angle of trim α^* and the float loading A*, which diminished from the total weight of the seaplane at zero speed to zero at take-off. A third curve F gives the wetted area, which includes also the sprayed area during unsticking. With this data the frictional correction can be calculated, it is the difference between frictional resistance of the full scale and the model aircraft. A check of this method is possible by virtue of the fact that the corrected resistance ($W_{H\ corr.}$) minus the frictional resistance (W_R) must approximately equal the horizontal component of the normal force on the float bottom, *i.e.*, be equal to the normal resistance W_N, which is the product of $A^* \times \alpha^*$.

The described application of resistance to the full scale aircraft can also be effected so that the relative roughness of the full scale float is greater than that of the model. To this end the "equivalent roughness" according to the roughness of the full size must be known. This can be estimated by a method of Schlichting (*Ingenieur-Archiv.*, Vol. VII., 1936, No. 1). The coefficient of friction can be then calculated according to the Prandtl-Schlichting formulae for rough plates.

Stability Problems.

Porpoising.

In the first place a phenomenon observed with naval aircraft will be discussed, which may lead to the destruction of the aircraft. If at a certain speed during take-off the pilot pulls or pushes the stick in order to increase or decrease the angle of trim, sudden and strong vibration will be experienced similar to those known as flutter of wing or tail unit. This lack of stability due to oscillation in heave and pitch is called porpoising. It is an excited coupled oscillation which can appear also on a smooth water surface. One has to distinguish a "main oscillation" introduced by forces and moments due to change of wetted area and angle of incidence, and a "secondary oscillation," 90 degrees out of phase, due to change of direction of flow owing to causes interconnected with the main oscillation. Forces and moments in phase with the main oscillation can be positive or negative. If they are positive and greater than those out of phase, porpoising

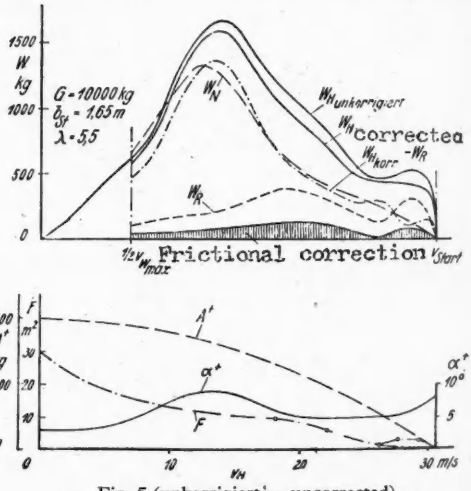


Fig. 5 (unkorrigiert = uncorrected).

will result. In Fig. 6 the angle of incidence is plotted against the speed, and the upper and lower limits of stability are shown for two loading conditions. The figure is self-explanatory and clearly shows the stable zone within which the take-off curve must lie. The limits of this zone depend in the first place on the float (or hull) shape and on its loading. With increasing load the limits move to higher angles of incidence. For take-off with an overloaded aircraft the angle of incidence must be greater than with normal load.

One of the main tasks of research is to determine the zone of stability. Apart from the model tests, the theory of small oscillations provides a method of calculation (Perring and Glanert, A.R.C. Report, R. & M., 1493, 1942). In Fig. 7 a comparison of results for full scale testing, model testing and calculation is given. For the lower limit of stability all three results are in good agreement. For the upper limit, however, especially at lower speeds the deviation is marked.

Naval aircraft built in Germany are stable in the planing condition. The pilot must, however, take precautions to avoid porpoising. A great help in keeping the correct trimming angle is afforded by an indicator from which the angle of trim can be read off and compared with the required angle.

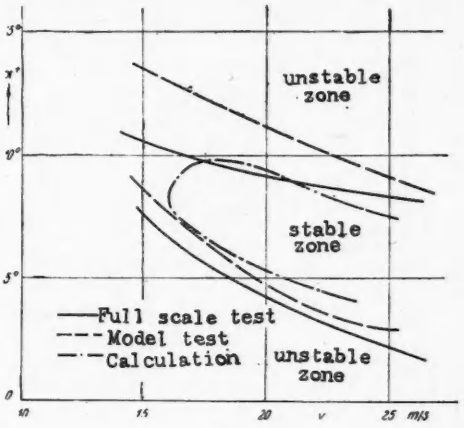


Fig. 7

Floating Stability.

These problems enter the picture when hydro- and aerodynamic forces are negligible in comparison to the hydrostatic forces; namely when the speed of the floating aircraft is zero or small.

Wind which can attack the floating craft from all sides induces forces and moments. These conditions can be reproduced on models when a ground plate represents the water surface and the forces and moments are measured.

For the design of flying boats the question of lateral stability is especially important, as the dimensions of sponsons, or wing tip floats, depend on it. Fig. 8 should serve to illustrate this. Index I. belongs to a flying boat with stubs, Index II. to that with wing tip floats. The restoring moments M_I and M_{II} about the longitudinal axis are plotted against the sloping angle. The inclination of tangents of the moment curves serves as an indication of the degree of static stability. The metacentric height λ of normal position is represented by the tangent at $\varphi = h$, and Fig. 8 shows that the two flying boats have greatly differing metacentric heights, i.e., their initial stability is different. It will be shown that in spite of an equal capsizing moment M_{max} the two flying boats react to side winds in different ways. The disturbing moment M_W due to side wind is shown in the figure and it increases slightly with φ as can be seen. This is due to the increased area of attack at greater angle of tilt. Aircraft I reaches a state of equilibium at angle φ_I(°), whilst aircraft II at φ_{II}(°) under a much greater angle which, combined with a strong seaway, may become dangerous. The difference becomes more pronounced with increasing wind strength such as a gust when the angle shifts to φ_I and φ_{II} respectively. When this state is reached the kinetic energy of the disturbing moment is transformed into potential energy of the restoring moment. The oscillation set up are eventually damped out and the aircraft reaches an equilibrium as given by angle φ(°). The energies are represented by the moment areas, and for gust the geometrical condition for maximum sloping angle is equality of the disturbing and the restoring moments. The condition is fulfilled if, as in the figure, the shaded areas are equal. For aircraft I a further increase in wind velocity is possible, i.e., with increasing M_W the area between the M_W– and the M_I curves above the M_W– curve does not become smaller than that below the M_W curve. This is not so with aircraft II., where an increase in wind velocity leads to capsizing.

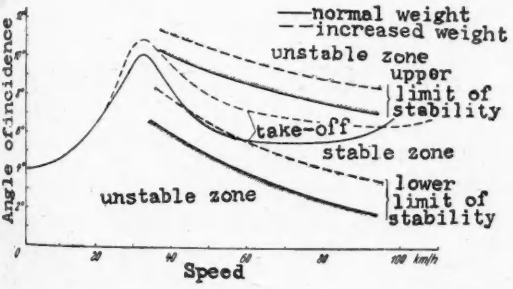


Fig. 6

(*To be continued*).

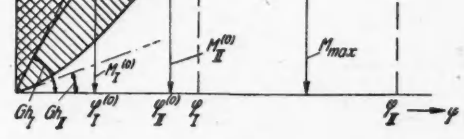


Fig. 8

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Announcements in this section include News relating to British Firms, and on Equipment produced by British Manufacturers.

Available literature may be secured by addressing a request to the advertising department of "The Engineers' Digest," or by writing direct to the manufacturer and mentioning "The Engineers' Digest" as a source.

- NEW EQUIPMENT
- BOOKS AND CATALOGUES
- BUSINESS CHANGES
- PERSONAL
- NOTES

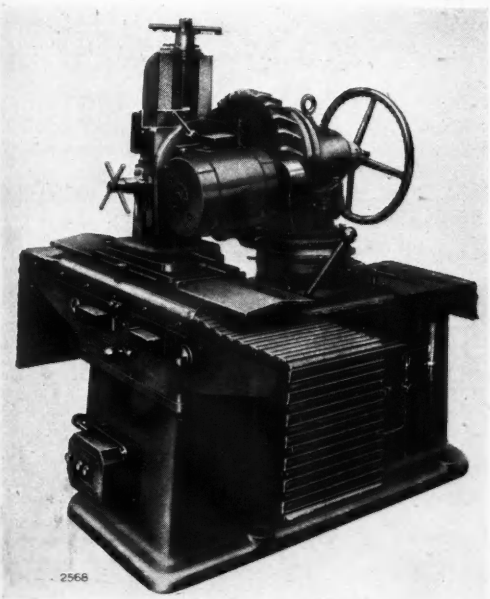
NEW EQUIPMENT

FACE MILLING CUTTER GRINDING MACHINE.

FACE milling machines, whether of the plano or vertical type, cannot work efficiently unless their cutters are accurately ground.

Realising the importance of correctly generated, true cutting edges in order to obtain maximum output for minimum power used, Messrs. Kendall and Gent (1920) Ltd., Victoria Works, Gorton, Manchester, have designed and manufactured in recent years a large number of Face Milling Cutter Grinding Machines. The illustration shows the latest design of these machines

The grinding head of the machine, supported on a column which is arranged to swivel 20° to each side of normal, consists of a 1½ h.p. motor and a grinding wheel directly fitted to the shaft. Vertical and horizontal screw adjustments are provided with additional 45° swivelling to each side of the centre line. Auxiliary hand adjustment by rack and pinion and quick acting locks to all adjustments are provided.



The maximum diameter of face cutter ground is 30", the diameter of faceplate 14", and the speed of the motor is 3,000 r.p.m.

The machine, a number of which will shortly be available for delivery, can be fitted in a space of 7' 6" × 3' 6".

SILVER IN ALLOYS FOR AIRCRAFT APPLICATION.

RESEARCH carried out in U.S.A. on silver containing magnesium alloys indicate possibilities for the application of such alloys in the aircraft production. A recent magnesium alloy contains 2.6 per cent each of aluminium and zinc, 5.5 per cent silver, and 0.2 per cent manganese, and had a specific gravity of only 1.89. In extruded bars, rolled sections, and large forgings, it is reported to have the following physical properties after suitable heat-treatment: tensile strength 40,000 to 65,000 lb. per sq. in.; yield strength 32,000 to 50,000 lb. per sq. in.; elongation 2 to 10 per cent; Brinell hardness 80 to 95.

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CATALOGUES RECEIVED

The Venwick Contour Projector is described in the new Catalogue Sheet, No. S.T. 21, issued by Messrs A. C. Wickman Ltd., Coventry. Particulars are given of the general construction of the apparatus which includes the base, body, illuminating stage, condensing system, mirror, focussing mechanism, screen and object holder. The varying amount of adjustments and movements obtained allow for a wide range of jobs of various sizes and shapes to be examined. Three projection lenses are supplied, $\times 10$, $\times 25$, and $\times 50$. It is claimed that the lenses give excellent definition and are particularly suitable for screw thread work.

Self-Adhesive Tapes for Manufacturing Processes.—Self-adhesive tapes, originally brought out for the purpose of sealing and repair of documents, have found ever increasing application in manufacturing processes. They contribute in a number of operations to speeding up the production. Self-adhesive tapes are to-day generally used for aircraft riveting and all kinds of small riveting ; marking of electric conduits, cables and pipes ; sealing of tanks ; masking of sensitive parts during manufacturing process ; binding the ends of pipes to keep out foreign matter during transit or manufacture ; packing of cordite and other high explosives, sealing of bomb shells, etc.

Self-adhesive tapes are made of cloth, paper, and cellulose, in a range of colours, and Messrs. Industrial Tapes, Ltd., 52, Margaret St., London, W.1., will be glad to be consulted on questions regarding its application in Industry.

Maintenance Instructions for Oil Circuit Breakers.—In view of the fact that a large number of factories have now installed one or more Oil Immersed Circuit Breakers to control the increased load due to present-day conditions, it has been timely to issue general Maintenance Instructions to help to ensure that periodical maintenance is given to such static apparatus. Messrs. J. G. Statter & Co. Ltd., 82, Victoria Street, London, S.W.1, have recently published such Maintenance Instructions which may be obtained free upon application.

Tool Tipping and Hard Facing.—War on the present gigantic scale has led to a demand on the one hand for alloying elements far in excess of their availability and on the other hand for the absolute necessity for reclaiming worn parts of machinery, especially when replacement parts and labour for carrying out the necessary dismantling and re-erection work are difficult to obtain.

A booklet recently published by Messrs. Murex Welding Processes Ltd., Waltham Cross, Herts, illustrates the scope and value of the electric arc process of depositing layers of hard metal on machine parts to make them resistant to wear and abrasion, and also in certain other cases to provided cutting edges.

Considerable economies can frequently be expected and experience has shown that in some applications the reconditioned parts can withstand service conditions better than the original parts.

The booklet gives examples of a dozen typical applications of hard facing to engineering tools and other materials ; it also gives details of the degree of hardness which can be expected from deposits of different Murex Electrodes ; and some classification of the electrodes according to the type of work for which they are suitable. These types range from lightly alloyed electrodes used for reinforcing medium carbon steels and railway tracks, to austenitic alloy electrodes used for building up lips of dredger buckets and manganese rail crossings ;

ACCELERATION IN LINKWORK

By W. R. Thomson, B.Sc.Tech., A.M.Inst.C.E.—Engineers will find in this valuable book more information on the ways of motion in mechanisms than could be obtained from text-books on the theory of machines. It gives a sound foundation of first principles. Alternative methods of velocity and acceleration analysis are developed, and a suggested simple method of mechanism synthesis is put forward to aid the understanding of complex mechanisms. Many fully worked examples show the application of the various methods, while as a basis of comparison of these methods one standard example of the quadric cycle mechanism has been used throughout. 21s net.

PRINCIPLES OF IGNITION

By J. D. Morgan, D.Sc.—This book is one which will interest those engineers concerned with combustion engines and the prevention of explosions in mines and factories. It describes briefly and simply the principal facts relating to the ignition of inflammable gas mixtures by sparks, flames, incandescent solid particles, and other localised sources. 12s 6d net.

ELECTRIC CIRCUITS AND WAVE FILTERS

By A. T. Starr, M.A., Ph.D.—A textbook for telegraph engineers, wireless engineers and advanced students who wish to obtain a clear and comprehensive grasp of the fundamental principles of wave filters. 25s net.

VIBRATION IN MACHINERY

By W. A. Tuplin, D.Sc.—This book gives a general review of the fundamental principles of the subject, and forms an invaluable introduction to the more highly technical publications devoted to vibration theory. It deals with multi-mass vibratory systems, and analyses the external vibration-exciting influences with particular reference to torsional vibration in engines at critical speeds. The principles of various types of dampers and absorbers are explained. Further chapters deal with the use of flexibility to diminish vibration, the actual measurement of vibration, and finally, machinery failures due to vibration. The appendix gives some useful formulae and tables for guidance in design. 7s 6d net.

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and also electrodes suitable for giving weld metal of about 600 Brinell hardness. One of the latter type of electrodes is particularly suitable for cutting applications, such as woodworking tools, shearing blades and dies, where the cutting edge is not subjected to high temperatures ; while another deposits a metal similar to high speed steel and is suitable for tipping mild steel shanks to form lathe tools. The use of such tipped tools should be a boon to every tool room in view of the restriction of tool steels.

In order to obtain complete satisfaction, it is most essential that the correct type of electrode be used for each application and the Murex technical organisation is available for this advice.

BOOKS RECEIVED.

Handbook of Heating, Ventilating and Air-Conditioning.—By John Porges. George Newnes Ltd., London, August, 1942, 17/6. This excellent handbook consists of data sheets and useful tables conveniently arranged in loose leaf form. Each section is separately numbered, and additional pages can thus be inserted in the suitable place. Sheets needed by the heating engineer many times a day may be taken out from the folder altogether. This applies especially to the six folding charts of the handbook (Pipe sizes for all types of heating, Duct sizing for ventilation, Humidity of air, Degree day map of Gt. Britain). Space is provided for additional sheets to be issued so that the handbook can always be kept complete and up-to-date. The author is a Czech engineer.

Engineering Thermodynamics. By C. E. Lucke. Columbia University Press — Sir Humphrey Milford, Oxford University Press. Seventh Impression. Cloth, 6 × 9 in., 1188 pp., 53/6. The strain imposed upon engineers engaged in work vital to our war production, does not facilitate the study of voluminous books. However, an even superficial perusal of this book conveys the impression that it would prove to be a most useful addition to the reference library of many engineering firms. No space has been saved at the sacrifice of clearness and utility. Formulas are given in such form as to be readily available for numerical substitution. A very considerable number of large tables, numerous original diagrams, and charts which are certainly time-saving and extremely useful in everyday's practice are included.

TIN AND ITS USES.

The current issue of *Tin and its Uses* (No. 13), published by the Tin Research Institute, is devoted to emergency economies in tin. During the period of scarcity the Institute offers its services in the solution of tin economy problems. Accordingly, this issue describes practical methods of saving tin in various fields of use. For example, it is shown that important economies can be effected in joining lead-sheathed cables, both by using a solder less rich in tin and by the use of a new type of joint requiring not more than one-third the quantity of solder needed for the traditional wiped joint. A saving of the order of 99 per cent can be effected by using a cup and cone type of joint on lead pipes instead of the usual wiped joint. The ends of the pipes are shaped to male and female cones which are then sweated together with solder foil. A standard lead pipe joined in this way with only 0.05 oz. of solder withstood a pressure of 1,130 p.s.i.

Another article describes the advantages of thinly coated electrolytic tinplate as a substitute for ordinary tinplate in the present emergency.

An article on "Bearings with less Tin" reviews the recommendations made by the Technical Advisory Committee of the Ministry of Supply. This issue also includes a discussion of the pros and cons of a war-time

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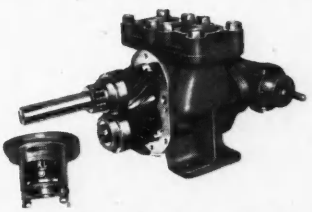
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extension of de-tinning, and some notes on recent American experience in soldering cans made from thin electro-tinplate.

Tin and its Uses is obtainable free of charge from the Tin Research Institute, Fraser Road, Greenford, Middlesex.

British Institution of Radio Engineers. At the September meeting of the Institution Dr. James Robinson read a paper on "Aspects of Modulation." His main purpose was, he said, to investigate possible means of increasing the efficiency of our use of the ether, from the point of view of accommodating the greatest number of communication channels in the available spectrum. He reviewed and compared methods used, and discussed their qualities. Beam transmission, which effected an economy in a geographical sense; single-sideband transmission, which effected a 50 per cent. saving in the spectrum with a considerable economy in transmission power; and suppressed carrier transmission, which was not suitable for general broadcasting work. He did not think the answer lay in wired broadcasting. The relative merits of amplitude modulation and frequency modulation occupied the major part of the paper, with special reference to the author's "Stenode" system as applied to transmission and reception, the demodulation of a weak signal by a strong one at the detector being explained in detail. He showed mathematically and by diagrams what happened to a frequency modulated signal when it was interfered with by an amplitude carrier. This paper was preceded by the inaugural address of Sir Louis Sterling on assuming the Presidency of the Institution. Sir Louis strongly advocated the registration of radio engineers, and also dealt with the methods which should be adopted to secure specialised technical training.

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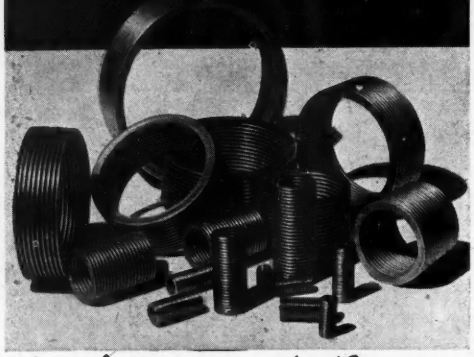

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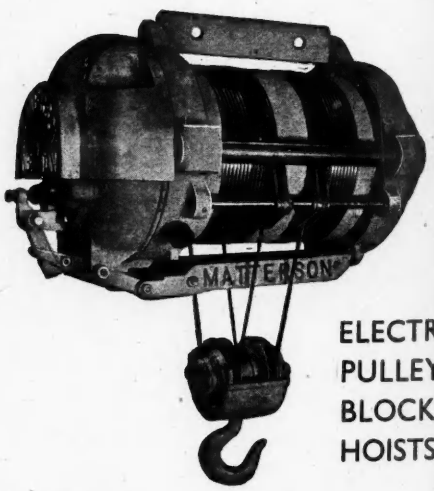

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